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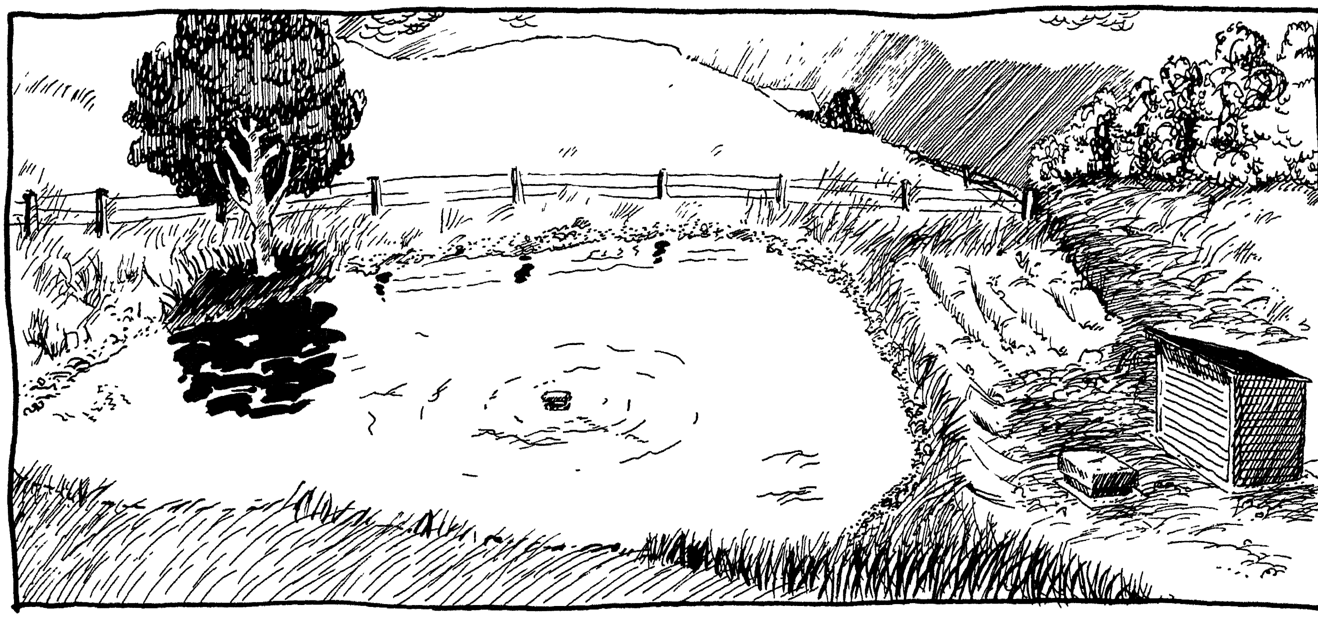
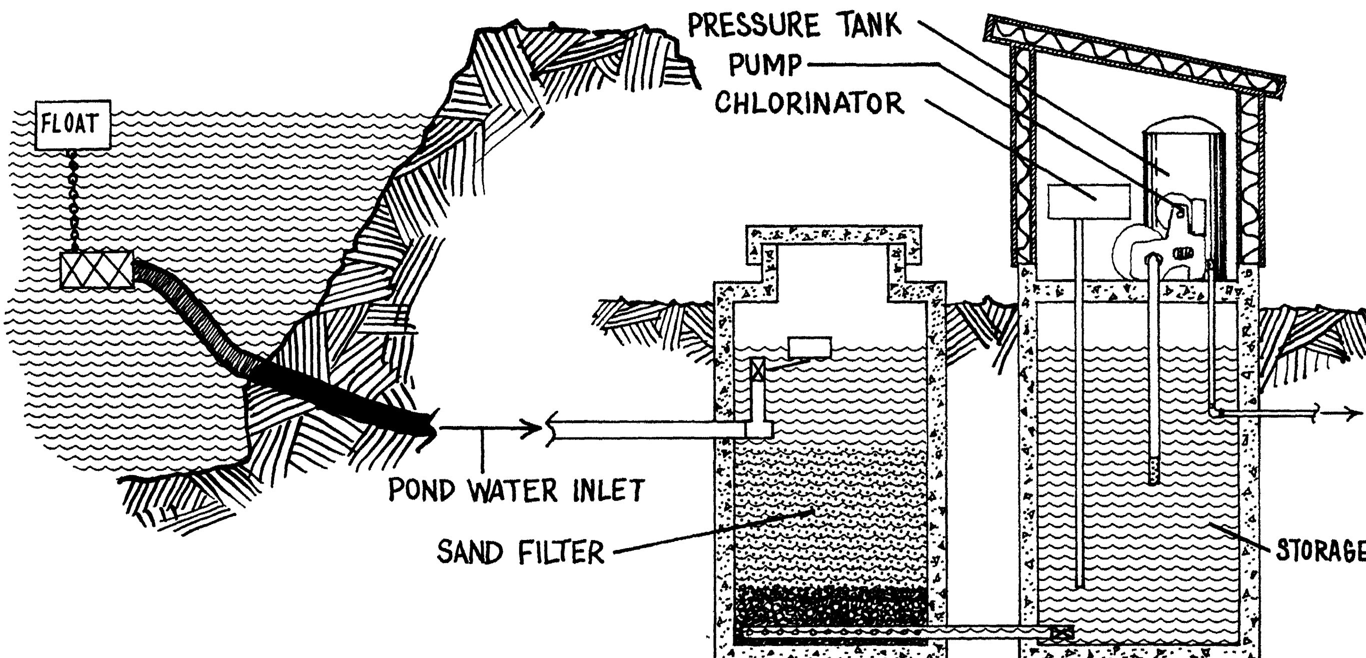
EVALUATION OF POND WATER TREATMENT SYSTEMS





by

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ACKNOWLEDGEMENT

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EVALUATION OF POND WATER TREATMENT SYSTEMS

by R.D. Hill, G.W. Malaney,
G.O. Schwab and H.H. Weiser*

INTRODUCTION

Water supply problems have become critical to many farm and suburban dwellers in Ohio. The trend toward larger farm units with greater numbers of livestock per unit, confined housing of livestock, pipe line milkers, bulk milk tanks, on-farm processing, and modern household equipment has increased water usage on the farm. Water sources in many cases are not adequate for this increased demand because of insufficient quantity or poor quality water. Cisterns are not capable of storing water for large farm operations. Dug wells are often contaminated and go dry in the summer. There are large portions of Ohio in which well yields are five gallons per minute or less due to poor underground water resources. The modern farm cannot have water just part of the time, but must have a sufficient supply of safe water 365 days of the year. The search for other sources of water have led many to the farm pond--first, as a livestock water supply, and later as supplemental household, milk house, and barn supply, and in some cases as a domestic water supply. With the popularity of farm ponds today (estimated at 35,000 in Ohio at the end of 1962 and being built at the rate of 2,000 per year) their increased use as a water supply can be expected.

This bulletin is the second in a series dealing with research on developing methods of treating farm pond water for domestic purposes. A previous bulletin (5)** dealt with the quality of water in Ohio farm ponds. Reported here are the results of a four-year (1958-1962) evaluation of pond water treatment systems on private farms. The water source for each of the treatment systems was described in the above mentioned bulletin.

In order to obtain information as to the effectiveness of individual water treatment systems and the major problems encountered in their operation, a study was made of twelve farm constructed and operated pond water treatment systems. The purpose of this evaluation was to determine areas that needed further research and to gather data for making design recommendations for such systems.

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** Numbers in parentheses refer to references listed at end of report.

PROCEDURE

Where possible water samples were taken before and after each treatment device, i.e., intake, disinfection unit, and filter. Samples for bacterial analysis were placed on ice immediately after being taken. These samples remained under refrigeration until analyses were made in the laboratory, usually within 24 hours. The only measurements made in the field were temperature and chlorine residual.

The analytical methods were:

Turbidity--determined with a Hellige Turbidimeter precalibrated to the Jackson candle.

Color(apparent)--measured using a Hellige aqua analyzer in which the sample was compared to precalibrated colored disks.

Chlorine (residual)--determinations made with a Taylor slide chlorimeter. Readings made within ten seconds after ortho-tolidine was added were taken as the amount of free available chlorine.

pH--measured by a Beckman pocket pH meter during part of this study. However, this method was discontinued because results were not reproducible. The subsequent procedure adopted was a phenol red indicator (pH range 6.8-8.4) in conjunction with a Taylor pH slide comparator.

Odor--detected by smell and classified as follows: no odor, perceptible, and objectionable. A sample having a faint odor, but not considered objectionable, was classified as perceptible. Any sample having a strong odor or an objectionable odor was classified as objectionable.

Coliform bacteria--estimated by the conventional multiple-tube MPN method described in Standard Methods (6). The procedure employed three tubes of lactose broth per dilation and three dilutions per sample, starting with 10 ml portions. Positive presumptive tubes were confirmed in brilliant green lactose bile broth.

Enterococci--density was estimated by the conventional MPN method, using Winter-Sandholzer media and three tubes per dilution, starting with 10 ml portions.

Thermophilic bacteria--population estimated by the standard plate count (SPC) technique as outlined in Standard Methods for the Examination of Dairy Products (7), with incubation at 55° C.

Thermoduric bacteria-- density estimated by the laboratory pasteurization test as described in Standard Method (7), i.e., the water sample was heated at 145° F. for 30 minutes in a David Bradley home milk pasteurizer, then the surviving bacterial population was determined by the SPC technique with incubation at 35° C.

Psychrophilic bacteria--density was estimated by the SPC method with incubation at 0-10° C.

Total bacterial population--estimated by the SPC technique with incubation at 35° C.

Chlorine contact time--the amount of time that chlorine was in contact with the water at each installation was calculated by using Baumann's data (3) on the efficiency of retention vessels commonly found in rural water supplies. The maximum flow rate of the system was used in this calculation because the samples were taken at this flow.

Ct factor--the product of the free available chlorine (mg/l) and the contact time (min.); as an example, 0.3 mg/l of chlorine and 20 minutes contact time would result in a Ct factor of 6 (0.3x20). The importance of this factor in determining the effectiveness of disinfection is illustrated in Figure 1 and discussed by Baumann and Ludwig(3).

The facilities of each pond installation are outlined in Table I. The data for each treatment system will be analyzed separately. In the discussion section of this report each type of treatment unit, i.e., intake, filter, and chlorinator will be considered separately.

RESULTS

Installation 1:

A flow diagram of the water treatment system at installation 1 is presented in Figure 2. The buried pipe intake was constructed by digging a trench on the bottom of the pond, laying a perforated pipe in it and backfilling with gravel. This intake performed poorly as the water it removed from the pond was high in color. Complaints were made by the homeowner about the yellow color and about a precipitate that was formed when soap was used. Heating the water intensified the color. This condition disturbed the owners to the extent that they stopped using the pond water in the house. For this reason the buried pipe intake was replaced by a commercial fiber glass surface intake. This intake was composed of a replaceable fiber glass cylinder suspended eighteen inches below the pond surface from a float (Fig. 4). The fiber glass removed the larger solids, such as filamentous algae.

Water flowed from the intake to the rapid sand filter (Fig. 5) by gravity. The filter medium was composed of a layer of gravel around the underdrain which was covered by a layer of filter sand (effective size 0.5 mm and uniformity coefficient 1.74) and then a layer of 4 inches bank-run sand. The filter was cleaned by removing the bank-run sand and replacing it. The period between cleanings was usually more than a year.

The owner considered this filter a slow sand filter, but there was no water storage after the filter and the discharge line was connected directly to a pump. Normal flow rate through the filter was 360 gpd(a)/sq.ft. surface area. This exceeds the 100 gpd/sq.ft. normally considered maximum for slow sand filters.

(a) gpd -- gallons per day.

TABLE I. Water Treatment Facilities at Each Installation

No.	County	Intake in Pond	Pump Size (HP)	Pressure Tank Size (gal.)	Primary Filter	Disinfection Equipment Chlorinator	Storage Before Treatment (gal)	Storage After Treatment (gal)	Other Treatment	Water Use
1	Delaware	Gravel trench[1] replaced 7/59 surface intake[4]	3/4 piston	60	Rapid sand[5]	Everclor	---	60	Everpure Dechlo-rinator	Household Livestock Milk House
6	Delaware	Barrel[2]	1/4 piston	40	None	Sureclor	---	---	---	Household Livestock[3]
8	Delaware	Barrel[2] replaced 7/59 surface intake[4]	1/3 jet	42	None until 5/60 press. rapid sand	Sureclor	---	None until 5/60 42	None until 5/60 Everpure Dechlo.	Household Livestock
23	Washington	Barrel[2]	1/3 piston	80	Rapid sand[5]	Everclor	---	---	Everpure Dechlo.	Household Livestock Milk House
25	Jackson	Barrel[2]	1/2 piston[6]	80[6]	Rapid sand[5]	Batch Installed Everpure 5/59 returned to batch	--	12,000	---	Household Livestock Milk House
26	Vinton	Barrel[2]	1/3 jet	40	Slow sand	Batch	---	4,300	---	Household Livestock
62	Highland	Block box	1/2 piston	40	None	Sureclor	---	---	---	Household
86	Lorain	Gravel box[7] replaced 7/59 surface intake	1/4	40	None	Sureclor	---	---	---	Household Livestock

TABLE I. cont'd

No.	County	Intake in Pond	Pump Size (HP)	Pressure Tank Size (gal.)	Primary Filter	Disinfection Equipment Chlorinator	Storage Before Treatment (gal)	Storage After Treatment	Other Treatment	Water Use
87	Lorain	Gravel box[7]	1/2 piston[6] 1/4 jet	40 20	None	Everclor	600	---	---	Household Livestock Milk House
88	Lorain	Gravel box[7]	1/2 jet[6] 1/3 jet	42 42	Press. Rapid sand	Everclor	5,000	---	Everpure Dechlo.	Household Livestock Milk House
89	Lorain	Gravel box replaced 7/59 surface intake	1/4 jet	42	Press. Rapid sand	---	---	---	---	Household, not drink. Livestock
90	Crawford	Gravel trench[1] replaced 8/59 surface intake	1/3 jet	42	Press. Rapid sand	Wallace Tiernan replaced 8/59 with BIF feeder	---	-42	Duro Press. Charcoal Filter	Household Livestock

1 trench dug in bottom of pond, perforated pipe laid in trench, and backfilled with gravel.
2 barrel intakes constructed from two 50-gal. barrels one on top of the other without tops or bottoms and filled with gravel. Perforated pipe ran through the lower barrel and unperforated pipe through the top barrel.
3 stopped using pond water in house 7/58.
4 surface inlet--inlet was suspended 1.5 to 3 feet below surface of pond.
5 based on flow rate.
6 first figures give size of pump and pressure tank used to pump water from pond to treatment equipment, second figures are for distribution pump.
7 a box made of concrete block filled with gravel at bottom of pond.

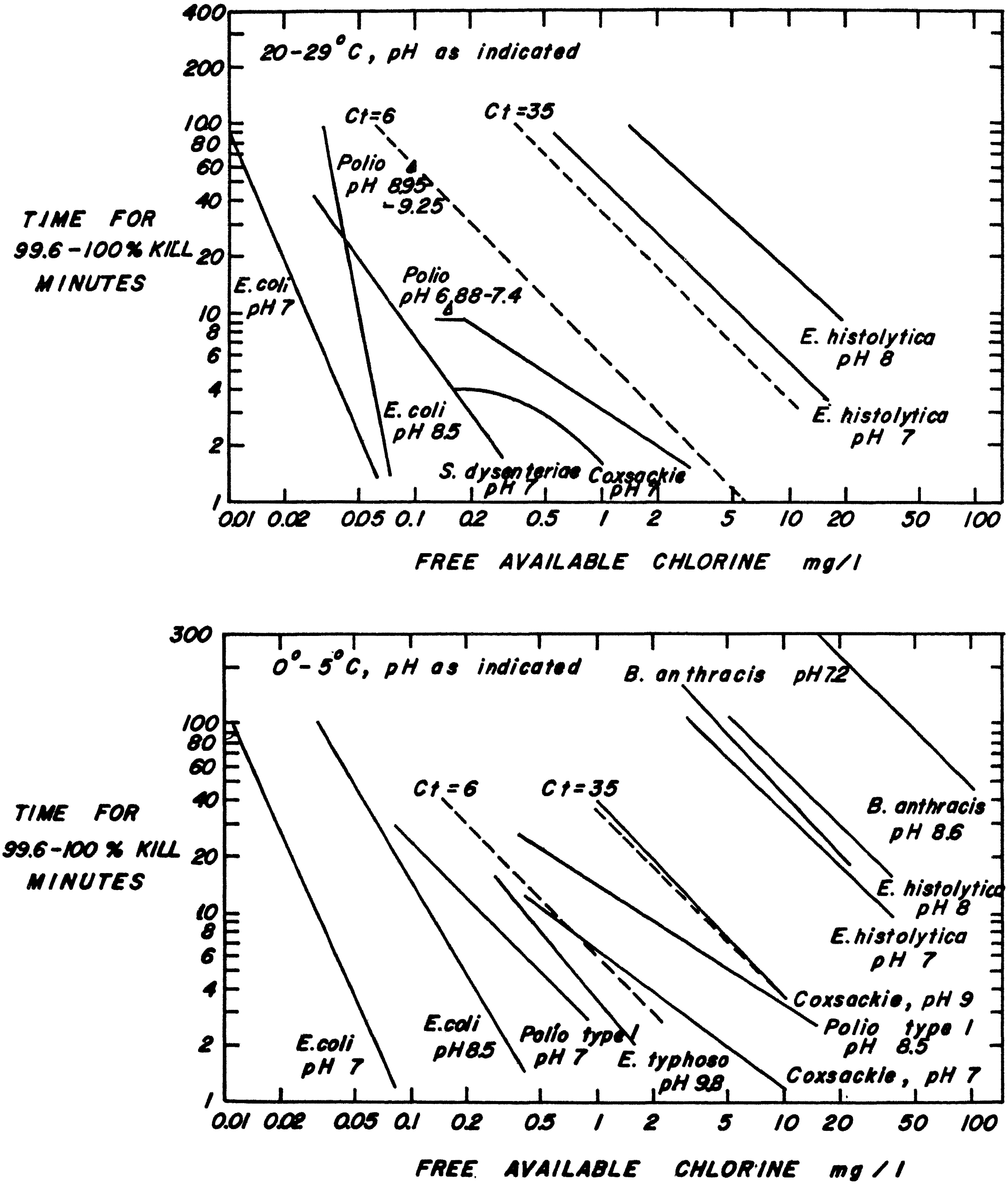

Figure 1. Destruction of microorganisms as a function of chlorine concentration, contact time, pH and temperature. (Graphs from publication by E.R. Baumann and D.D. Ludwig entitled, "Free Available Chlorine Residual for Individual Water Supplies," Iowa Engineering Exp. Sta. Proj. 353-S, 3/1/62.)

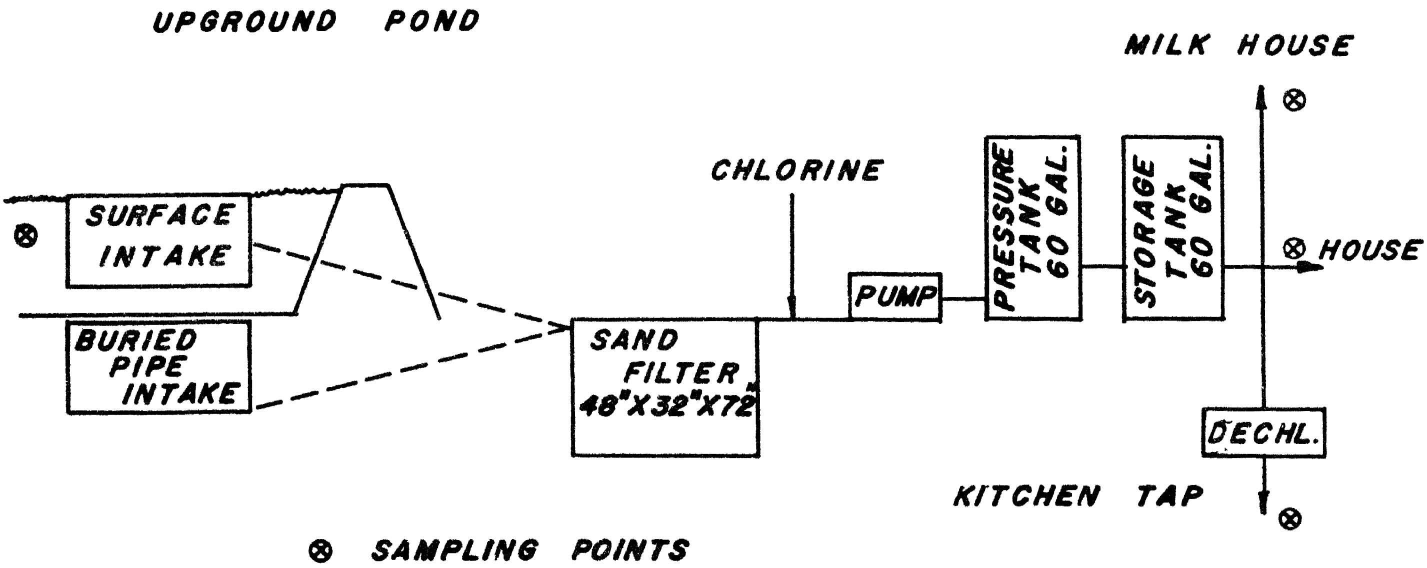

FIGURE 2. FLOW DIAGRAM OF WATER TREATMENT SYSTEM INSTALLATION NO. 1

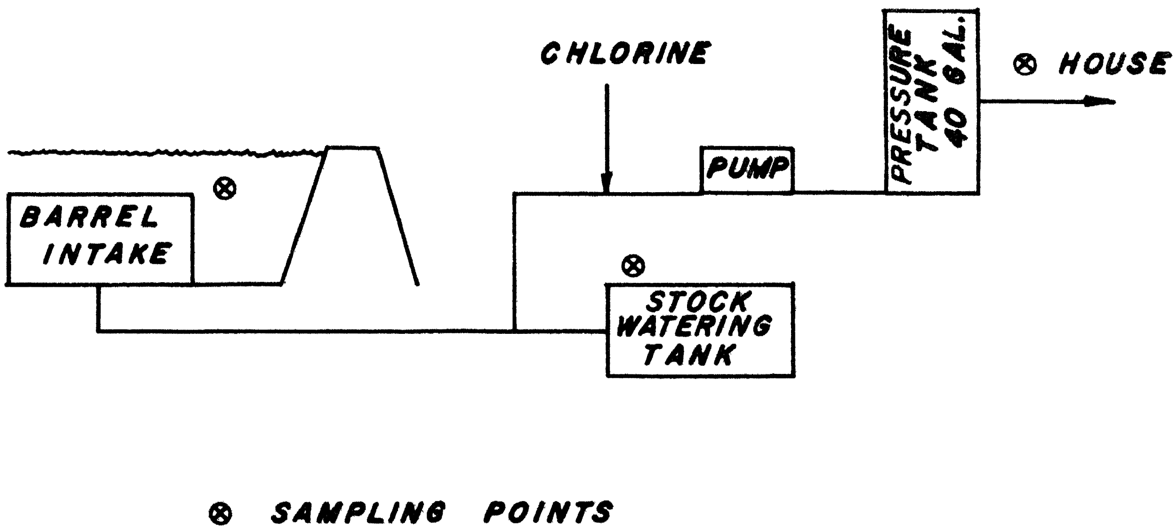

FIGURE 3. FLOW DIAGRAM OF WATER TREATMENT SYSTEM INSTALLATION NO. 6

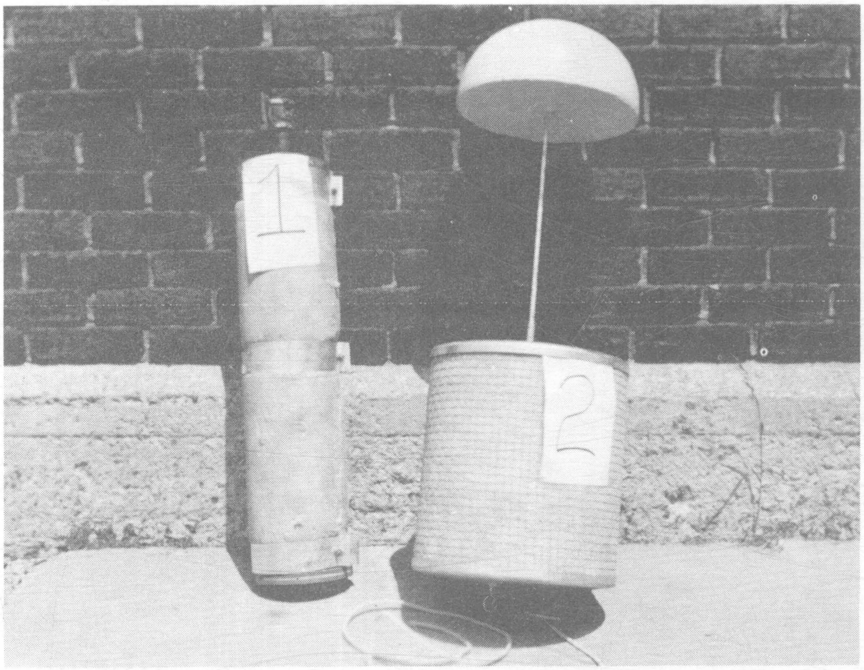

Figure 4. Surface Intakes: (1) one type of "homemade" intake which was supported by a 5-gallon can; (2) commercial intake.

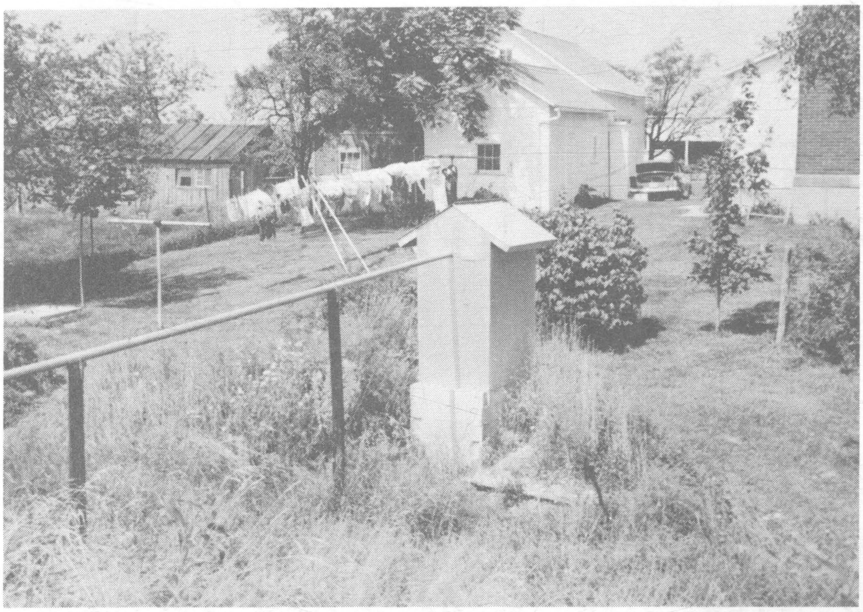

Figure 5. Installation 1: (1) on left hand side of picture the top of the slow sand filter can be seen. (2) Small stream from which water was pumped into pond is in front of pump house. Pipe line from pump house goes to pond.

Chlorine was fed to the water with an Everclor (b) interrupted suction type chlorinator. This type of chlorinator operates whenever the pump does.

The pump was followed by a 60-gallon pressure tank and a 60-gallon storage tank. Water used in the milk house, for livestock and at all taps in the house, except one in the kitchen, received no further treatment. The kitchen tap was supplied with a precoated carbon dechlorinator. This diatomaceous earth carbon filter is used primarily to remove chlorine and "polish" the water. A three cubic feet surface area filter was used. This filter is cleaned by removing the filter element and replacing it with a new one.

The pond used as a water source was one of the upground type. Water was pumped into the pond from a small intermittent stream during the spring of the year and during periods of heavy runoff in the summer (Fig. 5). The turbidity, color, and bacterial population in this pond was slightly below the average for Ohio ponds. (See OAES Bulletin 922 for complete discussion of this pond.) The average alkalinity of the raw pond water was 80 mg/l (a), the total hardness 151 mg/l, iron 0.54 mg/l, and pH 7.9. This pond had algal growth (Cladophora, Sperogyra and Chara) during the summer months.

Samples could only be taken in the pond, after the pump, and after the dechlorinator. Therefore, the effect of the intake, rapid sand filter and chlorinator was evaluated as one unit and the dechlorinator as another.

In ten samples before July 28, 1959, the turbidity near the intake averaged 40 units and the color 66 units. Water drawn in the house contained 15 units of turbidity and 131 units of color. The combination treatment by the intake and rapid sand filter resulted in a 63% reduction in turbidity and a 98% increase in color. The color was probably a result of the water picking up soluble organic material while it passed through the decayed organic matter on top of the intake. This organic matter was largely weeds and algae.

In 73 sets of samples taken over a 53-month period, the turbidity was reduced 45% and the color 6% by the intake and rapid sand filter (Appendix A). However, only 52% of samples met the drinking water standard of 10 units for turbidity and 58% met the standard of 20 units for color. In general, for the effluent water to be acceptable, the influent turbidity had to be less than 20 units. The findings for color were similar, that is, the effluent water was acceptable only when the influent water was of relatively good quality.

These results indicate that the rapid sand filter, when used without prior treatment such as coagulation, and not backwashed, is not an effective filter for pond water. The performance of this filter could have been improved by allowing gravity flow through the filter, and by

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(a) mg/l -- milligrams per liter.
(b) Names of commercial products are mentioned to clarify their description, but this does not constitute an endorsement by the Ohio Agricultural Experiment Station.

reducing the flow rate, by providing ample storage after the filter. Under these conditions the filter would have performed as a slow sand filter--a unit which has proven successful in pond water purification. The surface type intake gave better results than the buried pipe because of higher quality water at the surface of the pond.

From information taken from Baumann (2) the chlorine contact time for this system was calculated to be approximately 3.6 minutes. The free available chlorine residual for 68 samples had a median value of 4.5 mg/l. Sixteen percent of the samples had no chlorine residual. This usually occurred when the chlorinator was broken.

Twenty-six of 60 effluent house samples showed the presence of coliform bacteria (Appendix A). In this report a MPN of less than 3.0 coliforms per 100 ml is considered to represent the absence of coliforms. In six of these samples the chlorine residual was zero; however, in only two were the numbers of coliform organisms excessive. The remaining samples although showing coliforms contained between 0.1 and greater than 16 mg/l of free available chlorine. According to a report by Baumann & Ludwig(3) under ideal conditions coliform bacteria represented by E. Coli in their study should be killed by 0.1 mg/l of free available chlorine with 3.6 minutes contact time. However, in twenty samples with greater than 0.1 mg/l of chlorine, coliform bacteria survived.

The usual recommendation for bactericidal disinfection is 0.2 mg/l of free available chlorine for a contact period of 30 minutes. This is a Ct factor of 6. There is a safety factor in this recommendation to cover cases where the pH and/or temperature are not ideal for chlorine disinfection. From the information taken from Baumann (2) the chlorine contact time for the system at installation 1 was calculated to be approximately 3.6 minutes. In order for this system to have a Ct factor of 6, the chlorine residual must be 1.7 mg/l. Five contaminated samples had less chlorine than this and, therefore, the contamination in these samples could probably be explained by their low chlorine residual.

The remaining 15 contaminated samples had Ct factors ranging between 18 and 57. Contamination of one or two of these might derive from poor sampling technique, but it is highly unlikely that this would be true for all 15 samples. Other factors that would effect the efficiency of chlorine as a bactericide are pH and water temperature. Low temperatures do not appear to be the cause of ineffective disinfection because contaminated samples occurred even at temperatures in the seventies. For those contaminated samples in which pH determinations were made, the pH ranged between 8.0 and 8.6. Chlorine disinfection is not as effective at higher pHs, so this might explain some of the contaminated samples. It is highly unlikely that the pHs recorded would be the cause of contaminated samples when the Ct factor was 21 or more as it was in ten of the contaminated samples. In a few cases where the turbidity was high, the coliform bacteria may have been trapped in sediment particles and protected from the chlorine. Still there appears to be some unknown factors involved that resulted in the poor disinfection of these samples. The results suggest the presence of chlorine-resistant species of coliform.

The effectiveness of chlorine as a bactericide in destroying other types of bacteria than coliforms was investigated. The values given in Appendix B for pond samples taken one foot below the surface present a general picture of the bacterial density of the pond water. As pointed out by Hill, et al. (5), the bacterial population in pond water is generally low as compared with other surface waters. It would, therefore, be expected that the effluent water after treatment would have a low bacterial population, as it did. The bacterial densities in the effluent water would cause little or no concern in water for normal household uses.

Twelve samples were taken to evaluate the carbon dechlorinator. This piece of equipment removed turbidity and some color by filtration and chlorine and color by adsorption. Turbidity was reduced by this filter by 40% and color 90%. (Appendix C). Free available chlorine was reduced to zero in 70% of the samples. Chlorine was detected in the effluent water only after the filter units had been in operation a long period of time and under conditions of high influent chlorine residuals.

<u>Installation 6</u>:

Two 55-gallon drums, one set on top of the other, were filled with gravel and used as an intake for the water system at installation 6 (Fig. 6). The only other treatment this water received was chlorination with a Sureclor aspirator type chlorinator (see flow diagram Fig. 3.) Shortly after this investigation began, the home owners stopped using the pond water in the house due to its poor quality. Following this, samples were taken from a stock watering tank below the pond. Two samples were obtained with the chlorinator in use and on both occasions the chlorine residual was zero. It was observed at the time that the flow of chlorine was restricted by a precipitate in the chlorinator. The precipitate was a result of the reaction of chlorine and the iron of the solution water, and the hardness of this water. However, even after cleaning a residual was not detected even though the concentration of chlorine being fed was increased to 5120 mg/l (theoretical concentration in treated water 26.6 mg/l). The reason was undoubtedly the high chlorine demand of the water. The water on July 31, 1958, was high in turbidity and color and had some odor. The high chlorine demand was probably due to organic matter in the water as indicated by the high color and odor, derived from algal growths in the pond.

The barrel type inlet reduced the turbidity only slightly, and increased the color in 48% of the samples. This was probably due to the water picking up soluble organic substances from decaying algae and weeds that had settled into the intake. Although the average reduction of turbidity was 22%, only 52% of the samples actually showed a reduction in turbidity.

<u>Installation 8</u>:

The water treatment system at this installation was altered three times during this study.

<u>System A</u>

The original system installed by the home owner before this study began was composed of a gravel-barrel intake (similar to the intake at installation 6 and shown in Fig. 6), Sureclor chlorinator, 42-gallon pressure tank and 42-gallon storage tank (Fig. 8).

The barrel intake was the only equipment in this system capable of reducing the suspended solids in the water. The effluent from this intake, however, had a high concentration of turbidity and color as indicated in Appendix A. For this reason the owners replaced the barrel intake with a surface intake in July 1959. The surface intake was constructed from a section of perforated pipe wrapped with fiberglass sheet and screen. A galvanized pipe was driven into the bottom of the pond and the intake attached to it.

While the barrel intake was in use, the average effluent turbidity and color were 23 and 71 units, respectively. The intake reduced the turbidity concentration 57% and the color 10%. The surface intake reduced the turbidity only 12% and the color 5%, but the average effluent turbidity was the same as that from the barrel intake (23 units) and the color concentration was less (35 units). It is apparent from these results that the advantage of the surface intake lies in that it removes a higher quality water from the pond and not that it filters more efficiently.

The only other treatment device in this system was a chlorinator. The contact time between the chlorine and water was calculated to be 1.7 minutes. In order to obtain a desirable Ct factor of 6, a chlorine residual of 3.5 mg/l (6/1.7) was necessary. However, the average chlorine residual was 1.5 mg/l with a maximum of 5.0mg/l. The failure to maintain an adequate chlorine residual and/or contact time resulted in 53% of the samples being contaminated with coliform bacteria.

System B

The poor quality of water being obtained in the house prompted the owners to improve their system. In May 1960, a pressure rapid sand filter and dechlorinator were added to the system (Fig. 8). The exchange media of a second hand water softener was replaced with filter sand having an effective size of 0.52 mm and uniformity coefficient of 1.5 (Fig. 7). The filter was 16 inches in diameter and had a valving system for backwashing. The dechlorinator was of the precoated carbon type.

In February 1961, the "homemade" fiber glass intake was replaced by a porous ceramic filter (a). The ceramic unit was 8 inches long and $3\frac{1}{2}$ inches in diameter with a filtering area of 106 square inches. It was suspended 1 to 2 feet below the surface. The owners cleaned the unit by removing, washing, and drying. A second unit was used while the first was being cleaned.

The performance of the "homemade" surface intake was not as good during this series of samples as it had been when System A was evaluated. The average turbidity of 14.5 units was better, but there was an increase of 4% over the turbidity in the pond. Color was increased 16% to an average value of 36 units. The increase in turbidity probably was the

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(a) Manufactured by Filtros Inc., East Rochester, New York.

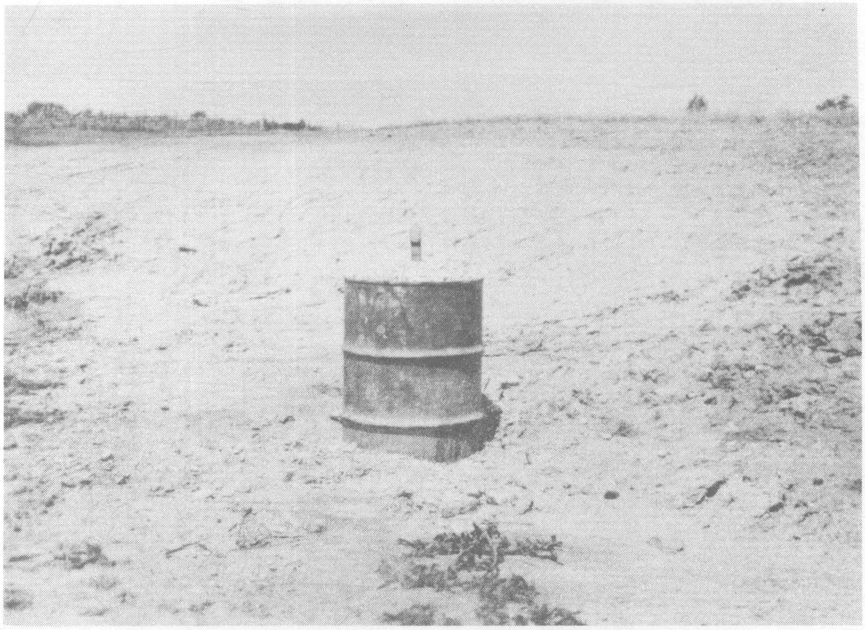


Figure 6. Typical barrel type intake. Such intakes are normally two drums high. (Photo courtesy Soil Conservation Service)

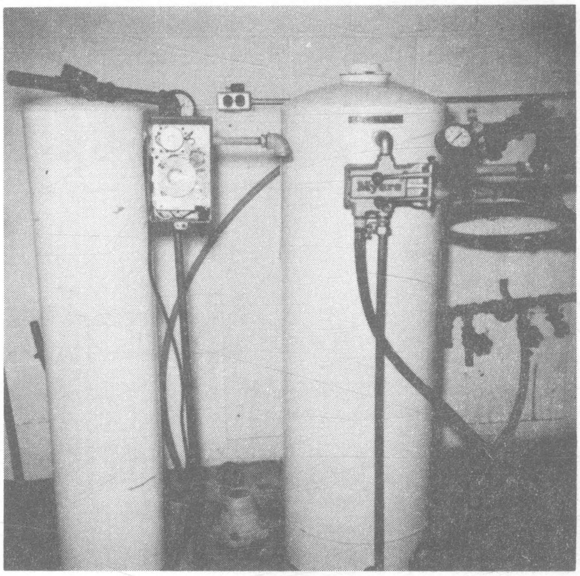


Figure 7. Typical pressure sand filters. Many companies manufacture filters similar to these with the major difference being the backwash mechanism. Filter on left is automatically backwashed and filter on right, manually.

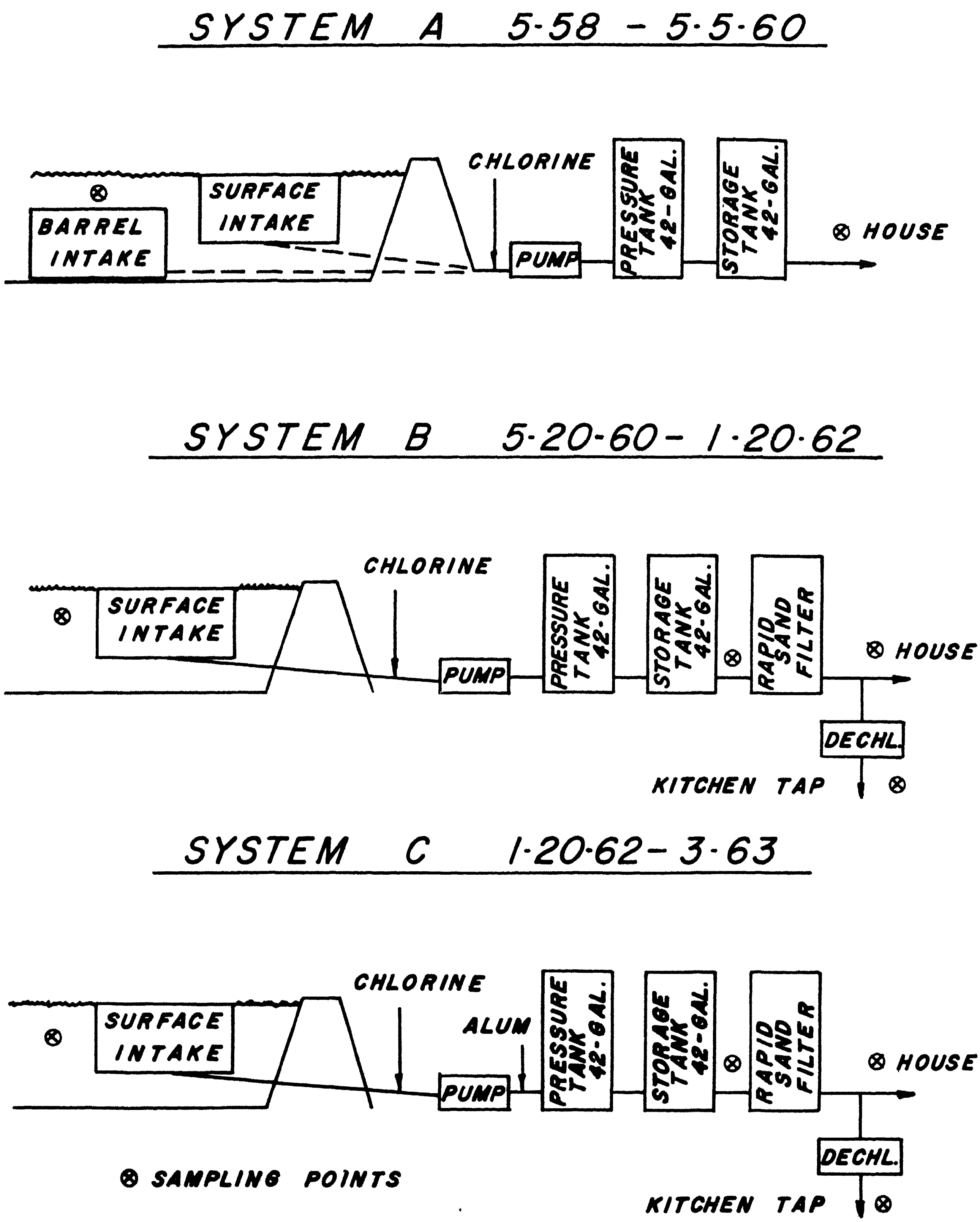


FIGURE 8. FLOW DIAGRAM OF WATER TREATMENT SYSTEMS
INSTALLATION NO. 8

result of sediment accumulating on the intake and later being washed into the system.

The ceramic intake did not perform as well as the "homemade". The average effluent turbidity was 27 and color 48, representing a 15% and 31% increase, respectively over that of the raw pond water. As in the case of the "homemade" intake, it appeared that sediment collecting on the intake ultimately was drawn into the distribution system.

The maximum flow through the sand filter was 2.5 gpm or 1.8 gpm per square foot surface area. Backwashing of the filter was normally performed once a month at a flow rate of 7 gpm for 25 to 60 minutes, depending on the time it took the water to clear up. The filter accounted for a 45% reduction in turbidity and a 40% in color while producing a water with an average of 10 turbidity units and 23 color units (Appendix A). Eighty-one percent of the samples met the Standard (8) for turbidity and 72% for color.

The sand filter also acted as a good dechlorinator. On the average the chlorine residual was reduced 88% from the average influent residual of 1.64 mg/1. Only on one occasion was the effluent chlorine residual greater than 1.0 mg/1.

The addition of the sand filter to the system increased the chlorine contact time by over 9 minutes, resulting in a total contact time of 11 minutes for the water at the kitchen tap. The samples taken of the influent of the filter had an average contact time of 1.7 minutes. Of these samples 58% were contaminated while only 20% of the effluent samples contained coliform bacteria. Although the filter removed most of the chlorine, the additional contact time as the water passed through the filter improved the bacterial quality of the water. The presence of coliform organisms in a few of the samples even with relatively high chlorine concentration and adequate contact time might be explained by (a) sample error, (b) chlorine-resistant bacteria, or (c) growth of coliforms in lower part of filter.

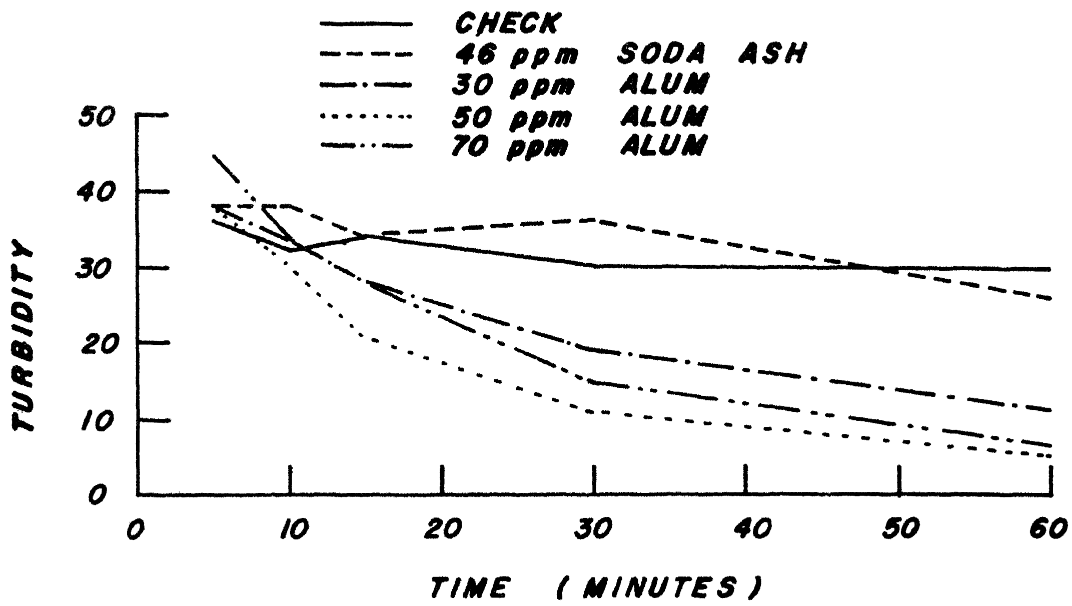
System C

The effluent of System B at certain times of the year was still not satisfactory. The pressure rapid sand filter was not capable of reducing the turbidity and color to an acceptable level during periods when the raw water was high in suspended solids. It also appeared that the particles that contributed to the suspended solids were very small in size and difficult to filter.

Laboratory studies were initiated to determine methods of improving filtration by increasing the size of the suspended solid particles. Jar studies were made in which a number of flocculating agents were applied to raw pond water from this installation. Alum at a concentration of 50 mg/1 proved to be the best material (Fig. 9).

On January 20, 1962, a diaphragm chemical pump was installed to feed alum to the system between the pump and pressure tank. The alum supply was a slurry formed by adding 12 pounds of alum to 48 gallons of water (30,000 mg/1) in a plastic tank. The foot valve of the pump was attached to a float in the plastic tank so that sediment would not clog the pump.

WATER SOURCE BEFORE FILTER - 3/7/63
STIRRING RATE - 155 RPM
STIRRING TIME - 5 MINUTES
AID NO. HAGAN COAGULANT AID NO. 952
MATERIALS ADDED AT TIME 0



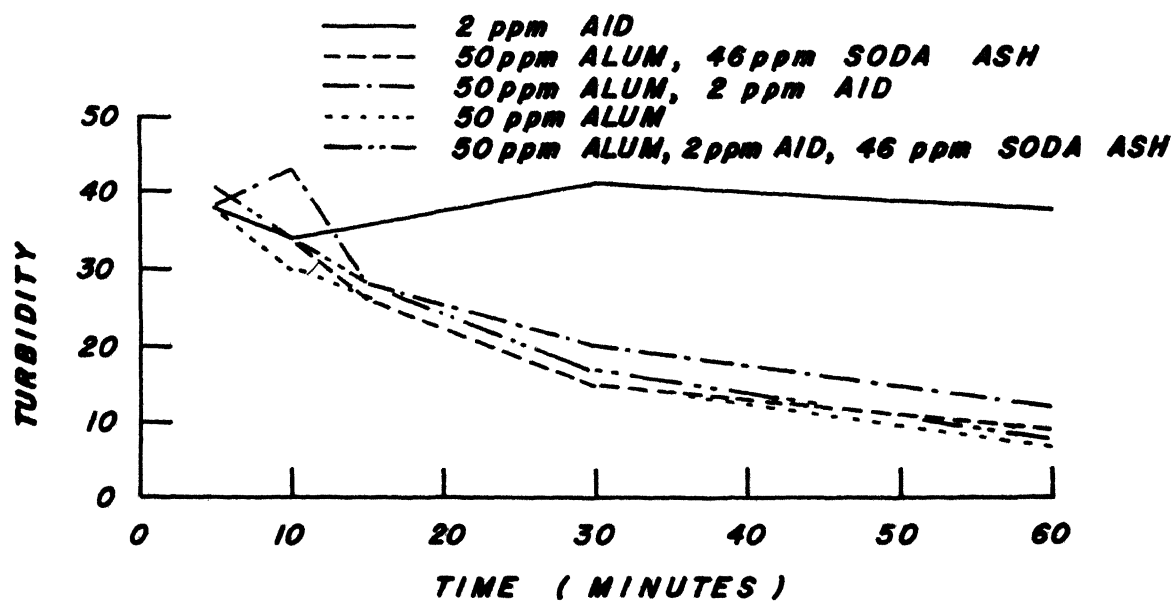


FIGURE 9. FLOCCULATION AND SEDIMENTATION STUDIES

INSTALLATION NO. 8

Tests made at the installation indicated that an alum dosage of 80 mg/l produced the best quality water. Approximately 0.3 gallons of alum slurry was fed per day. The addition of the alum increased the turbidity and color of the filter influent above the concentrations found in the pond. However, the filter was able to remove 82% of this turbidity and color. The effluent water contained 44% less turbidity and 58% less color than the raw pond water. On three occasions the turbidity did not meet the Standard (8). In two of these cases the alum dosage was probably not sufficient, as indicated by the small increase in turbidity of the filter influent.

This method then showed some improvement over the filter without pretreatment. One disadvantage noted was the lowering of the pH from approximately 8.0 to 7.1. On a few occasions it was lowered below 6.8. Further research is needed to improve this method which appears to be an essential requirement if the pressure rapid sand filter is to be made suitable for domestic water systems.

The contact time for System C was the same as for System B. The lowering of the pH by the alum should have resulted in the chlorine being more effective as a disinfecting agent. Four of the filter influent samples were contaminated, which was probably a result of the short contact time. The additional contact time supplied by the filter may have contributed to the reduction in coliform population in three of these samples even though the filter eventually reduced the chlorine residual by 95%.

Samples taken between April 1961 and March 1963 to evaluate the general bacterial population indicated that the bacterial density in the raw water was relatively low and that the treatmentsystem reduced the density only a small amount. In a few cases the treated water had higher densities than the raw water. The thermoduric, thermophilic and psychrophilic population of the treated water were at satisfactory levels, while the total population was slightly higher than that recommended for milk house water supplies (1). The enterococci and coliform densities were in agreement with each other except in a few cases where coliforms or enterococci were present in small numbers in the absence of the other groups.

A dechlorinator was used in both Systems B and C. The average turbidity and color of the dechlorinator effluent met the Drinking Water Standards (8) in all but a few occasions. These occurred when the effluent from the sand filter had high concentrations of turbidity and color. This indicates that the suspended matter was of such nature that it was difficult to filter. It would seem that the particle size was very small since it was able to pass through the sand bed, as well as the fine pores of the diatomaceous earth-carbon layer in the dechlorinator. Chlorine was removed readily by the dechlorinator. In only one sample was free available chlorine detected. Samples taken just after the unit was installed indicated that the dechlorinator was recontaminating the water, possibly because the unit was contaminated during installation. In less than a month the contaminating bacteria must have died, as the water was uncontaminated again. A similar situation developed when the filter was recharged.

The dechlorinator was effective in the reduction of turbidity, color, and chlorine. Its major disadvantage was the short time it took to clog the filter to the extent that an unsatisfactory flow rate was obtained. The cost of the recharge cartridges was the reason given by the owners for not correcting this situation sooner than they did. Great care should be taken in recharging these units to avoid contamination.

Installation 23:

The raw water at installation 23 had the highest turbidities of any pond studied (5). The turbidity was composed of fine clay which did not settle easily, and was difficult to flocculate because of the low pH (between 5 and 7) and alkalinity (avg. 8 ppm) of the water. The small clay particles also made the turbidity difficult to filter. The bacterial population of the water was also higher than that found in most Ohio ponds.

The barrel intake was similar to that at installation 6. This was followed by what the owner called a "slow sand filter" (see Fig. 12). However, there was no water storage after the filter and the water was pulled through the filter by a pump at rates up to 144 gallons per day per square foot of surface area. This flow exceeded that normally considered as a rapid sand filter. The remainder of the system is illustrated in Fig. 10.

The rapid sand filter was constructed from cement blocks and was 40 inches by 56 inches and 64 inches deep (Fig. 12). Gravel was placed around the underdrain system and covered with filter sand (effective size 0.51 mm and uniformity coefficient 1.49). The filter was cleaned by backwashing or by removing sand from the surface of the filter. Backwashing was accomplished by allowing the water in the distribution system, which was at a higher elevation than the filter, to pass back through the filter. It is doubtful whether this method was very successful because of inadequacies in flow rate, volume of wash water, and pressure that could be obtained in this manner. The filter became clogged to the extent that an insufficient flow rate was obtained in June 1958 and 1961 and in September of 1961. On the first two occasions two inches of sand were removed from the surface of the filter. This resulted in an increased flow rate. In September 1961, the filter sand was replaced.

Ordinary household bleach (sodium hypochlorite 5.25%) was used as a chlorine source. Frequent adjustment of chlorinator was necessary because as the filter became clogged the flow was reduced and the chlorine concentration increased to an undesirable level. The turbidity level of the water was usually high even after filtration, resulting in rapid clogging of the dechlorinator. The filter element in this unit was not normally changed even when the flow became as low as 0.1 gallon per minute.

The combination of barrel intake and rapid sand filter was not effective in reducing the turbidity and apparent color to an acceptable level. Only one sample was obtained that met the Drinking Water Standard (8) for turbidity and two samples that met the Standard for color.

This definitely indicates that a rapid sand filter of this type with no pretreatment, such as flocculation, and with an inadequate backwashing system is not effective in filtering pond water. The filter probably would have operated with better success if a water storage tank had been provided after the filter and the flow rate through the filter reduced to the range normally used in slow sand filters.

The contact time between the chlorine and water was calculated to be 9.8 minutes. The majority of the contact took place in 300 feet of pipe running from the pump to the house. The Ct factor ranged between 0 and 147. Seven of the 24 samples tested after chlorination were found to contain coliform bacteria. Four of the contaminated samples occurred when the chlorine residual was so low that a Ct factor at which coliform bacteria would be destroyed was not reached. Three samples showed coliforms even though they had a Ct factor of 39, 39, and 54. The high coliform density in the July 1960 sample indicates that this sample was probably contaminated after being taken. The remaining two contaminated samples might have resulted from the bacteria being entrapped in sediment and, therefore, protected from the chlorine. Even this does not seem likely at very high Ct factors and other factors may be involved.

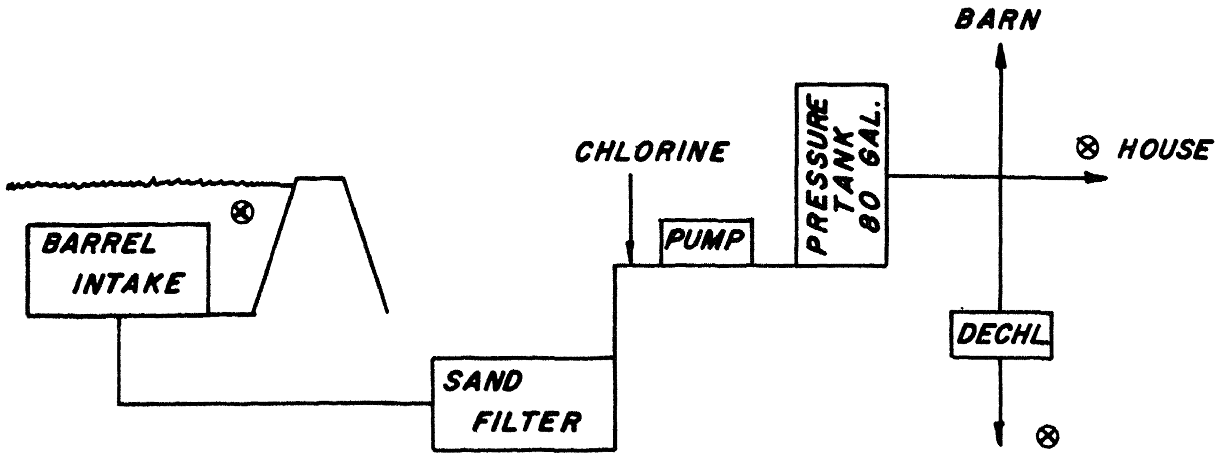
In 1961 five sets of samples were taken to evaluate the effect of this treatment system on other types of bacteria. The bacterial population of the treated water was rather low except in a few cases. The treatment system reduced the bacterial density of the water, but in general did not completely eliminate the bacteria. Small numbers of thermodurics, thermophiles,psychrophiles and enterococci remained. The enterococci results substantiate those for the coliform bacteria. On only one occasion were enterococci present in the treated sample and this occurred when there was no chlorine residual in the water.

The dechlorinator was effective in reducing turbidity, color, odor, and chlorine (Appendix C). In this situation the apparent color was caused primarily by turbidity and therefore, the result should not be interpreted to mean that this amount of true color would be removed by the carbon in the filter. The high concentration of turbidity in the influent water caused the dechlorinator to clog rapidly resulting in a low flow rate. A larger dechlorinator would eliminate some of this problem, but as long as the primary filter is not effective the dechlorinator life is short.

Installation 25:

The water treatment system at installation 25 is illustrated in Fig. 11. During part of this study, chlorine was fed to the water before the pump at the pond. Water flowed by gravity through the filter to a storage basin. A second pump supplied water to three houses, a milkhouse, and livestock.

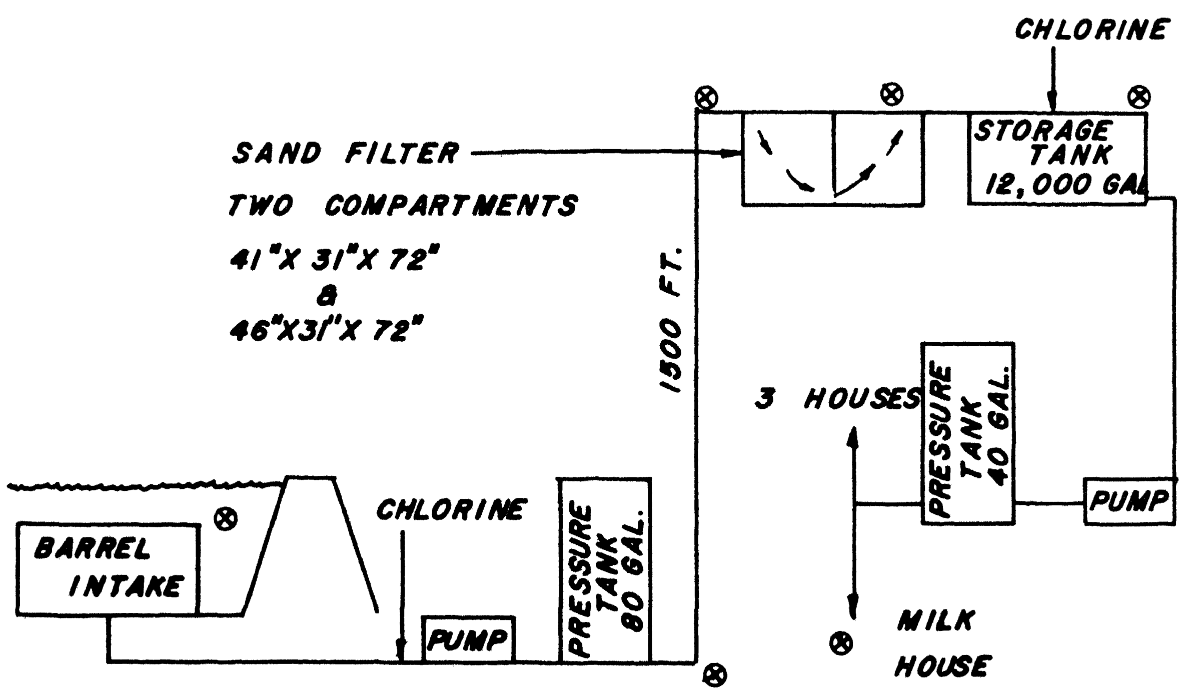
The filter was constructed as a slow sand filter, but actually was operated as a rapid sand filter since the flow rate ranged from 175 to 610 gallons per day per square foot of surface area. The filter had two compartments with the flow passing down through the first and up through the second (Figs. 11 & 13). Cleaning was accomplished by replacing the sand and gravel once or twice a year. At times charcoal was also added with the sand and gravel. Due to the heavy water demand, the filter operated continuously.



⊗ SAMPLING POINTS

FIGURE 10. FLOW DIAGRAM OF WATER TREATMENT SYSTEM

INSTALLATION NO. 23



⊗ SAMPLING POINTS

FIGURE 11. FLOW DIAGRAM OF WATER TREATMENT SYSTEM

INSTALLATION NO. 25

Figure 12. Installation 23. Sand filter located at foot of dam. Water flowed to filter by gravity.

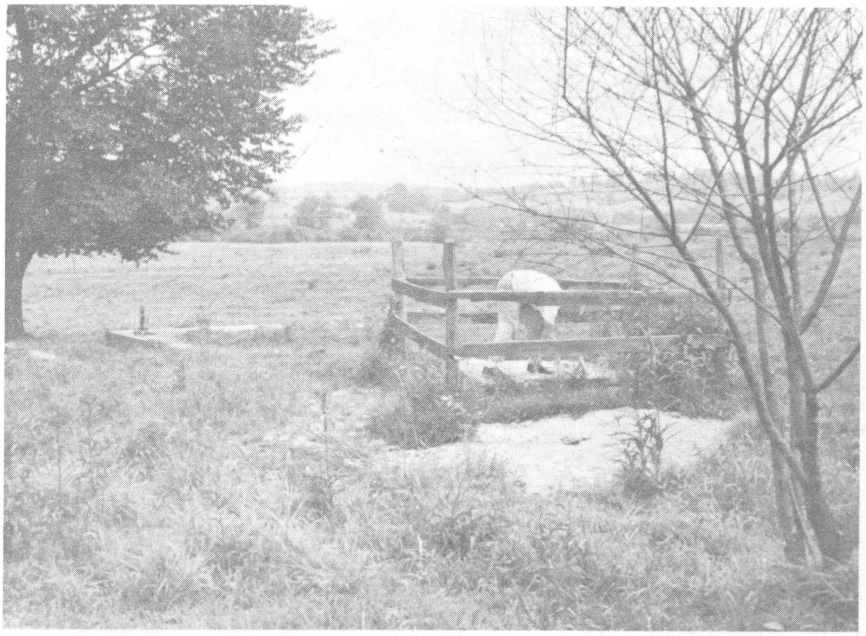


Figure 13. Installation 25. Sand filter located inside wooden fence. Clear well can be seen to the left of filter. Note that both are in a pasture and that only the filter is protected from livestock.

The storage basin following the filter had a capacity of 12,000 gallons. During the first year, as well as during the last few months of this study the water was chlorinated by adding to the basin 50% calcium hypochlorite at the rate of $1\frac{1}{2}$ cups every two days, or a cup every day. Assuming the storage basin was full (12,000 gal.) and ignoring any chlorine demand of the water, one cup of 50% calcium hypochlorite would yield a chlorine concentration of 0.16 mg/l and $1\frac{1}{2}$ cups a concentration of 0.25 mg/l. However, the water would have some chlorine demand and, therefore, the chlorine residual of the water would be expected to be less than these calculated values. This partially explains why no chlorine residuals were detected in the water at times. On the other hand, measurements made of the depth of water in the storage basin indicated that it occasionally held as little as 1,600 gallons. The usual dosage of chlorine at such times would have resulted in a higher residual. The high chlorine residuals detected in the water are probably due to this.

The sanitation around the storage basin was poor. The filter and storage basin were located in a pasture; the sand filter was protected from livestock by a wooden fence, but the clear well was not (Fig. 13). The manhole to the storage basin was built up about four inches; this provided protection from surface water. However, it was a common occurrence to find cattle manure on top of the clear well and there is a strong possibility that some of this material may have entered the basin.

In general, the physical properties of the pond water at this installation were of higher quality than the average, while the coliform and enterococci bacteria densities indicated somewhat poorer than average bacteriological quality (5). The turbidity and apparent color was not reduced to any large degree by the intake. Turbidity was reduced in 50% of the samples and color in 33%.

The sand filter was found to reduce the turbidity and color only a small amount. Turbidity was reduced in 46% of the samples and remained unchanged in 27%. Sixty-three percent of the effluent samples from the filter met the Drinking Water Standard (8) for turbidity. Effluent samples met the Standard only when the influent turbidity was less than 15 units. Similar results occurred in the removal of color, i.e., 59% met the Standard and relatively low influent color was necessary for this to occur.

Although the sand filter alone reduced the coliform bacteria density to some extent, the filter did not show an acceptable coliform index in most cases.

In the periods of July 1958 to July 1959, when the water was batch chlorinated at the storage basin, 50% of the finished water samples showed no free available chlorine. However, only one sample was contaminated with coliform bacteria. In this same period, only one sample taken in the basin was not contaminated. There is no apparent reason for this. In general, the batch method of chlorination was unsatisfactory because of lack of control (the owner had no equipment to measure chlorine residual), the difficult if not impossible task of batching a system in continuous operation and the unpredictable chlorine demand and flow rate of the water.

On July 30, 1959, an interrupted suction feed type chlorinator was installed at the pump below the pond. It was connected at this point in order to take advantage of the contact time available in the 1500 feet of pipe between the pump and sand filter. The chlorinator was adjusted until a chlorine residual of 2 parts per million was obtained at the pump. In subsequent samples, residuals much lower than this were detected. The chlorine residual in all but one case had been reduced to zero by the time the water had passed through the sand filter. Coliform bacteria were not destroyed.

A bacterial analysis of the raw and finished water was made in 1961. As shown in Appendix B, there was little if any reduction in the thermoduric, thermophiles,psychrophilic and total bacterial populations by the treatment system.

Installation 26:

The water system at this installation is shown in Fig. 12. The filter depth was not known by the owner, but was estimated to be 4 to 6 feet (Fig. 16). The filter medium was sand and charcoal of unknown quantity. Flow rate could not be determined because of inaccessible pipes. The filter had been installed in 1950 and as of March 1962 had never been cleaned. The water was chlorinated in this storage basin that followed the filter by adding $\frac{1}{2}$ tablespoon of 24% chlorinated lime or one quart of laundry bleach every two weeks. The amount of chlorine detected in the water varied between 0.0 and 6.0 mg/l with a median of 0.0. Only eleven samples of the twenty-four taken contained a chlorine residual. It appears that the chlorine was lost to the demand of the water and/or was dissipated to the atmosphere in the two week period between additions of chlorine. Also, since water was continuously entering the storage basin, the chlorine content was constantly being diluted throughout the period.

Seventy-eight percent of the samples taken in the house contained coliform bacteria. Of the contaminated samples, 72% contained no chlorine residual. Five samples contained both chlorine and coliform bacteria. This seems completely unreasonable because of the long contact time available in the storage basin, however, the influent and effluent pipe in the basin were rather close together and it is not out of the realm of possibility that the water short-circuited through the basin. The result of this would be a much shorter contact time. This could explain the presence of coliform bacteria in samples with an adequate chlorine residual.

The combination treatment of the intake and sand filter resulted in a reduction in turbidity and an increase in color. Only 35% of the samples taken in the house met the Drinking Water Standard for turbidity and 52% for color.

The poor operation of the filter was likely a result of 12 years of no cleaning or maintenance.

During 1961 a brief study was made of the bacterial population of the raw water in the pond and of the finished water in the kitchen. As seen in Appendix B, the water treatment system had little effect upon

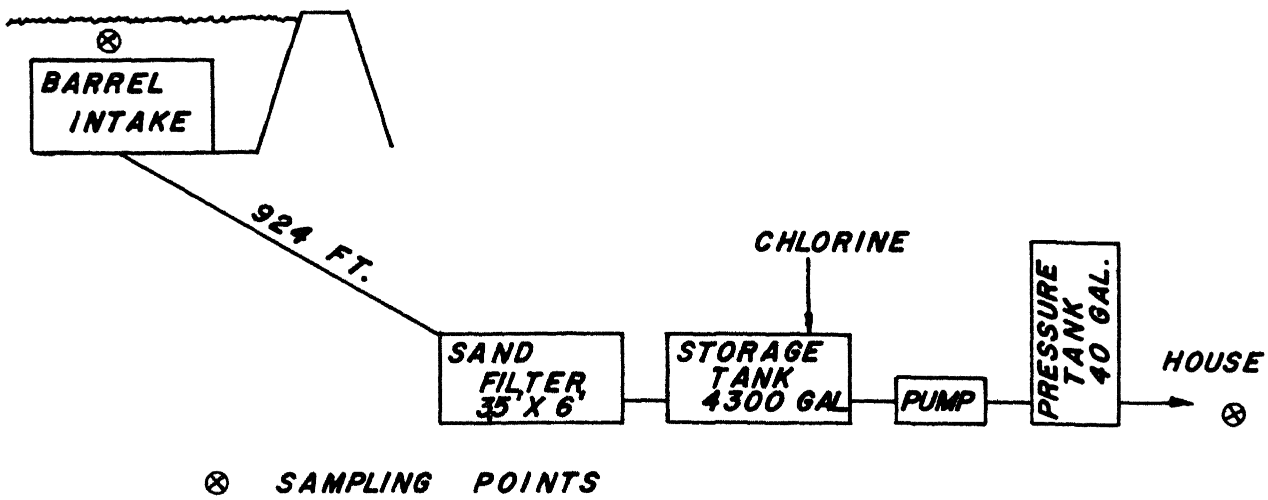


FIGURE 14. FLOW DIAGRAM OF WATER TREATMENT SYSTEM

INSTALLATION NO. 26

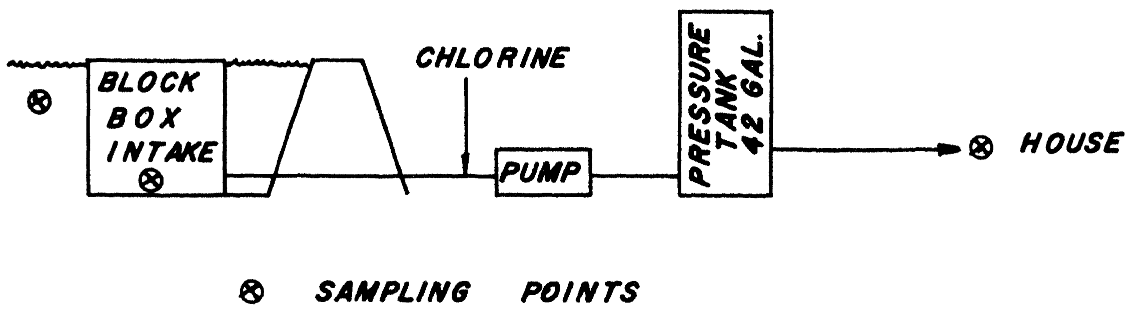


FIGURE 15. FLOW DIAGRAM OF WATER TREATMENT SYSTEM

INSTALLATION NO. 62

Figure 16. Installation 26. Filter on the left and clear well on the right. Water flowed from the pond to the filter by gravity.

Figure 17. Installation 62. Block box intake. This intake contained no gravel.

the bacterial population. In fact, in the majority of the cases the total bacterial count, thermoduric, thermophilic,psychrophilic and enterococci densities were greater in the finished water than in the raw water.

Installation 62:

The intake at installation 62 was a box 5 feet by 5 feet by 9 feet high, constructed of cinder blocks, extending from the bottom of the pond to a point 2 feet above the surface (when the pond was full) (Fig. 17). There was no filter media in the box. The intake worked on the principal that the pond water would be filtered during passage through the cinder blocks. Water was drawn from the intake by a pump in the basement of the house, where chlorine was added at the pump with a Sureclor injector type chlorinator (Fig. 15).

The physical quality of the raw pond water was higher than that found in most Ohio ponds, while the bacteriological quality was about average. Heavy algal growths were common in the summertime with mats of algae often found on the sides of the intake.

Over a 49-month sampling period, the intake decreased turbidity 31% and color 40%. Turbidity was reduced in 77% of the samples and color in 75%.

During the course of this study the mortar between some of the cinder blocks had come out leaving an open channel to the inside of the intake. This finding placed serious doubt as to whether or not the blocks were filtering the water. It was theorized that the box was acting as a settling tank, since the inside of the box was not affected to any great extent by wind and temperature changes, resulting in a condition favorable to good settling. On the other hand, no buildup of sludge appeared in the bottom of the box. However, since the effluent pipe was near the bottom of the box, sediment may have been drawn into the water system. This effect is indicated in some sample sets where the turbidity was higher in the house than in the intake.

Only in half of the sample sets taken outside and inside the intake was there a decrease in coliform density. This suggests that the intake was not effective in reducing the coliform density, but in light of the defective structure of the box, not too much faith can be placed in this conclusion.

Based on data by Baumann (2), the contact time between the chlorine and water was calculated to be 0.42 minutes. The chlorine residual of the water varied between 0.0 and 5.0 mg/l. This variation resulted partially from the variable chlorine demand of the water and from fluctuation in the dilution of the chlorine fed to the water. In general, the homeowner adjusted the dosage so that a chlorine odor was not detectable.

Thirty-two percent of the samples collected in the kitchen contained significant numbers of coliform bacteria. Fifty-six percent of the contaminated water samples contained no chlorine residual which explains why they were contaminated. The remaining contaminated samples contained between a trace (more than 0.0 but less than 0.1 mg/l) and 3.0 mg/l. These samples had Ct factors of 1.3 to less than 0.04. According to Baumann(3) a Ct factor of at least 1.0 under ideal conditions is needed to destroy Escherichia Coli (one species in the coliform group). It would seem that the lack of contact time and/or proper chlorine concentration was the cause of the chlorinated samples being contaminated.

The water in the house met the Standard for turbidity in 66% of the samples and for color in 82%. This usually occurred when the raw water was of high quality. The owners complained of unpleasant odors in the water during the summer months, which was attributed to excessive algal growths.

The water treatment used at this installation was not consistently effective in reducing the numbers of various bacterial groups of the water (Appendix B). The enterococci results substantiated those obtained for the coliform organisms.

Installation 86:

A concrete block box 4 feet by 4 feet and 3.5 feet high filled with gravel was used as an intake during the first part of this study. This was later replaced with a surface type intake. Water was drawn through the intake and to the house by a pump located in the basement of the house. A Sureclor chlorinator added chlorine to the water at the pump (Fig. 18). The concrete block box intake was essentially the same as a barrel-type inlet. The intake had little, if any effect, on the turbidity, and color increased upon passage through the intake. On occasions an odor was also present in the water after it had passed through the intake.

Eventually the water developed such high color and odor concentration that the owners replaced this intake with a commercial surface type intake (Fig. 4). Samples taken on July 11, 1958 from the gravel box and surface intake had the following characteristics:

gravel box intake-- turbidity-17; color-120; odor-yes; blue green algal-yes

surface intake-- turbidity-19; color-40; odor-no; blue green algal-no.

The higher turbidity for the surface intake can be attributed to the flushing of the new pipe line. The surface intake removed a higher quality water from the pond, thereby, reducing the color and eliminating the odor. Odor was never again detected in the water in the house and apparent color never reached the magnitude it didwhen the gravel box intake was being used.

The last 16 sets of samples were taken when the surface intake was in use. The intake was responsible for a 12% reduction in turbidity and a 24% reduction in apparent color.

The calculated chlorine-water contact time was 0.64 minutes. Free available chlorine was measured in the water in concentrations varying from 0.0 to 1.5 mg/l with an average of 0.4 mg/l. These residuals gave Ct factors ranging from 0.0 to 0.96. Because of this low value, 9 out of 21 samples showed the presence of coliform bacteria. All contaminated samples had some chlorine present, even as much as 1.5 mg/l.

As indicated in Appendix B, this treatment system reduced the total bacterial count, thermoduric andpsychrophilic bacterial densities somewhat, while the thermophiles increased slightly. The enterococci results verified those for coliform bacteria; for example, when coliform bacteria survived, enterococci did also.

It is apparent from the data obtained at this installation that treatment other than an intake in the pond and chlorination is needed to render pond water suitable for household use. The importance of providing sufficient chlorine-water contact time was also emphasized.

Installation 87:

Water was pumped from a concrete-gravel-box intake to a barn without further treatment for livestock use and to two cisterns for domestic use. A second pump removed water from the cisterns and supplied the house and milk house. The water was chlorinated at the second pump (Fig. 19).

One cistern had a capacity of 600 gallons while the second was 1600 gallons. When the water level became low in the cisterns, they were filled with pond water. Therefore, the cisterns functioned as settling tanks. However, the advantages of sedimentation were partially counteracted because the water was withdrawn from near the bottom of the cistern. The small cistern was cleaned every two years; the larger in 1958. An Everpure interrupted feed type chlorinator was installed at the second pump.

The pond and water system at this installation were constructed in late 1957 and early 1958. During the first two years the physical and bacteriological quality of the pond water was poor. After this period, the pond improved in quality resulting in a more desirable water source.

Since samples were not taken except in the pond and house, no evaluation of the affect of the intake and sedimentation-cisterns as individual treatment units could be made. A comparison of the raw water and the treated water quality on any one day were of no value in determining the efficiency of the treatment system, since the pond water may have been pumped into the cistern a number of days earlier. The raw water quality data did give an indication of the state of conditions in the pond during that period of the year.

During the early part of this study when the raw water quality was poor, it appeared that the treatment system did reduce the turbidity and color concentration to some extent, but in most cases not to an acceptable level. As the raw water quality improved, the treated water did likewise, but observed effects of the intake or cistern storage were not as pronounced. In general, results indicate only a minor removal of suspended solids and color when the water quality was poor. The amount of material removed increased as the quality decreased. Satisfactory domestic water was not produced.

Since the water was chlorinated upon removal from the cisterns, the only contact time between chlorine and water was obtained in a 20-gallon pressure tank and in 20 feet of pipe. The calculated contact time was 0.08 minutes. The chlorine residual of the treated water varied from 0.0 to greater than 9.0 mg/l. Fifty percent of 22 samples taken were contaminated with coliform bacteria. Three of the contaminated samples had no chlorine residual while the remaining samples varied in chlorine residual between 0.5 and 5.4 mg/l. At even the highest chlorine residual the Ct factor was only 0.43.

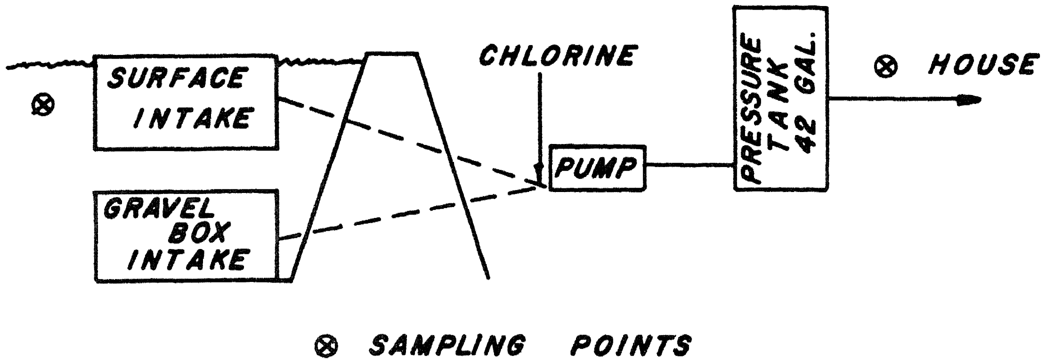


FIGURE 18. FLOW DIAGRAM OF WATER TREATMENT SYSTEM

INSTALLATION NO. 86

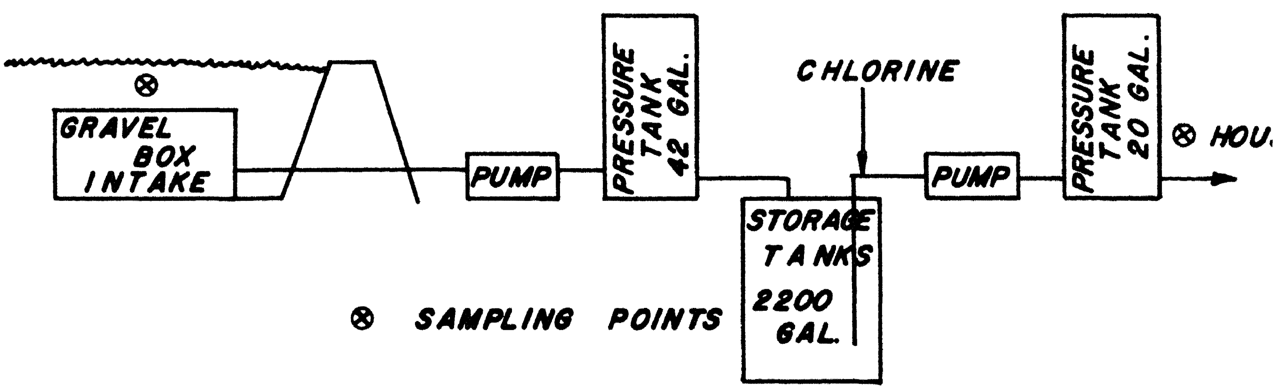


FIGURE 19. FLOW DIAGRAM OF WATER TREATMENT SYSTEM

INSTALLATION NO. 87

It was observed several times that the chlorine residual varied during a pump cycle. For example, on August 19, 1961, the chlorine residual ranged between a trace and 2 mg/l during one cycle. The chlorinator used at this installation feeds a "slug" of chlorine every few seconds. Unless good mixing occurs this "slug" of chlorine would pass on through the system. Mixing was not sufficient to produce a relatively constant chlorine residual.

In Appendix B the affect of this treatment system on the population of the various bacterial groups is presented. It appears from this data that the total bacteria, thermoduric and thermophilic density were reduced little if any by the system. The psychrophilic population seemed to be reduced to a greater extent. The short contact time was probably the cause of the poor kill of enterococci.

Installation 88:

A concrete block box intake filled with sand except for a layer of large stones on top was located on the bottom of the pond. Water was pumped from the intake to an old cistern which was used as a storage tank and settling basin (Fig. 20). Water was then drawn from the cistern, chlorinated and filtered by a pressure sand filter. No further treatment was given to the water other than dechlorination at one cold water tap in the kitchen.

From 250 to 330 gallons of water were used per day at this installation. The pond proved to have insufficient volume to satisfy this demand during the summer. Water depth in the pond was as low as two feet on a number of occasions. During these periods water was hauled from a nearby town and placed in the cistern.

The storage tank (cistern) operated in the same manner as that at installation 87. Water was used from the storage tank until it was about empty, then the tank was refilled with pond water. Some settling of sediment probably occurred in the tank, but once again the outlet was set near the bottom and some of the sediment may have been drawn into the distribution system. The storage tank was cleaned in 1957 and received no other maintenance during this study.

The manually backwashed pressure sand filter was similar to the ones at installations 8, 89, 90 (Fig. 7). The filter was 16 inches in diameter and had a rated flow rate of 5 gpm. There was no set frequency of backwashing, but was normally done every two to three weeks.

An Everclor chlorinator was used, and an Everpure activated carbon-diatomaceous earth dechlorinator was installed on a cold water tap in the kitchen. Water from this tap was used primarily for drinking and cooking.

Samples were obtained at three locations: (1) in the pond; (2) after storage, chlorination, and filtration; and (3) after the dechlorinator. From this data only the combined effect of storage, chlorination and filtration could be evaluated. This combined treatment resulted in an average effluent turbidity of 10 and color of 11 units (Appendix A). Fifty-five percent of the samples met the Standard for turbidity and 80% for color. Although no direct comparison can be made between the effluent and raw water, in general, it might be concluded from the data that this system did not reduce the turbidity and color to any great degree.

The chlorine contact time was calculated to be 4.8 minutes at 3 gpm. The chlorine residual varied between 0.0 and 8.0 with a median of 3.6 mg/l. Six out of 1[illegible] samples were contaminated. These samples occurred at chlorine residuals from 0.2 to 8.0 mg/l. A chlorine residual of 1.25 mg/l was needed to give a Ct factor of 6, which was considered necessary for good coliform destruction. All of the samples had Ct factors greater than this.

There are three possible reasons why the coliform were not destroyed: (1) excessive pH resulting in less effectiveness of the chlorine, (2) low temperature resulting in less effectiveness of chlorine, and (3) high turbidity in which case the coliform bacteria may have been lodged inside of a particle of sediment and, therefore, protected from the chlorine. The pH of four contaminated samples was recorded as 7.5, 8.1, 8.3, and 9.6. The pH of 9.6 is the only one that might have resulted in the chlorine not destroying the coliform. Four contaminated samples had temperatures in the sixties (61,62,64,69°F.), one in the fifties (54°F.) and one in the forties (49°F.). The sample at 49°F. was obtained when the water was being batch chlorinated and the chlorine residual was 0.2 mg/l. The contact time for this sample was a matter of days. It is unlikely that the temperatures were low enough in the remaining samples to cause coliform bacteria to survive when the chlorine residual was equal to or greater than 3.0 mg/l. Turbidity was less than 10 for all except two of the contaminated samples. The batch chlorinated sample (0.2 mg/l chlorine) had a turbidity of 21 units while a contaminated sample containing 8 mg/l of chlorine had a turbidity of 18. In the former case the turbidity concentration might explain the survival of the coliform bacteria, but this seems highly unlikely at 8 mg/l of chlorine. All indications are that either there were present chlorine resistant coliform bacteria and/or other chlorine-resistant organisms which gave a positive coliform test; or that there are other factors involved in chlorine disinfection.

Three samples were examined in 1961 for general bacterial population. The treatment system appeared to reduce the bacterial population but did not completely eliminate it. The low counts in the finished water would not be of significance in the normal usage of water in the home. The enterococci results, when compared to the coliform results, suggest that the enterococci were more resistant to chlorine disinfection than are the coliforms.

The dechlorinator was effective in reducing the turbidity and color to an acceptable concentration (Appendix C). In only one case for both turbidity and color was the Standard not met. In 65% of the samples the chlorine residual was reduced to zero. Only in cases where the influent chlorine was greater than 3.0 mg/l, and not even in all of these cases, was there a residual in the effluent. On seven occasions, the effluent contained coliform bacteria. In three of these the influent also contained coliforms. The remaining four samples must have been contaminated in the dechlorinator, even though they contained between 1.0 and 5.0 mg/l of chlorine when they entered the filter. The only explanation seems to be that at certain times coliform bacteria become established in the filter, probably the interior, where they are protected from destruction because the chlorine was removed at the exterior of the carbon layer.

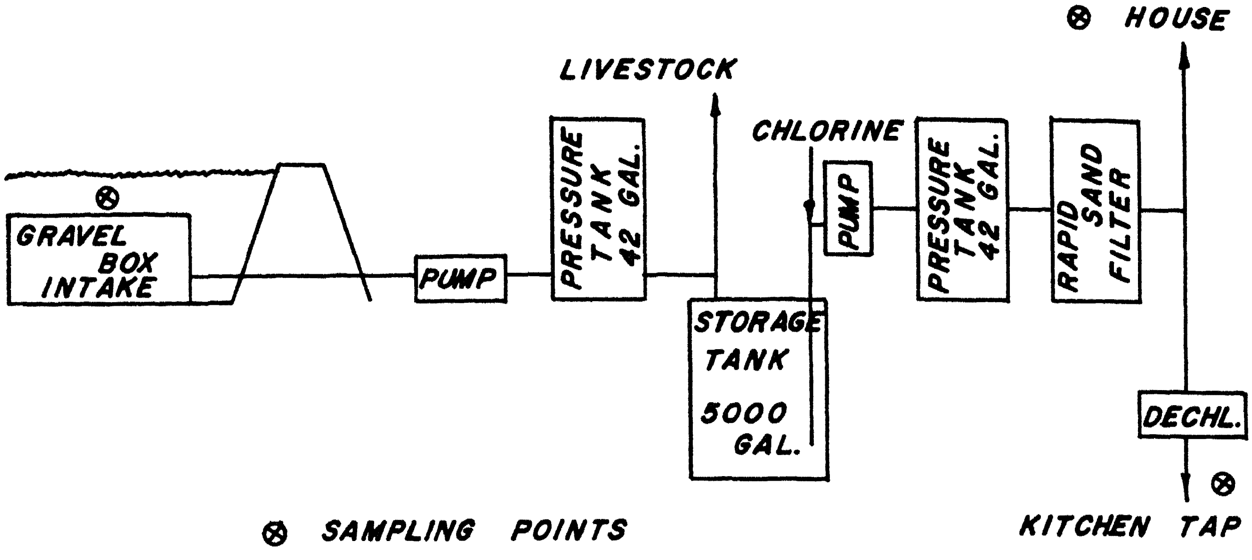


FIGURE 20. FLOW DIAGRAM OF WATER TREATMENT SYSTEM

INSTALLATION NO. 88

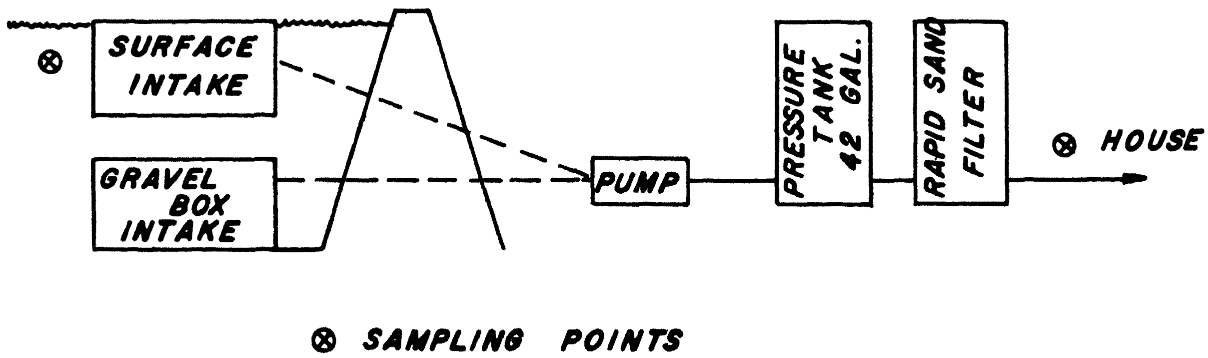


FIGURE 21. FLOW DIAGRAM OF WATER TREATMENT SYSTEM

INSTALLATION NO. 89

Installation 89:

A gravel box intake was being used at installation 89 when this study began. This was later replaced by a surface type intake. Water was drawn from the intake by a pump in the basement of the house and then pumped through a pressure rapid sand filter (Fig. 21). This water was used for all purposes in the house except cooking and drinking.

This pond contained some of the poorest water of any of the ponds studied (5). Color and odor were especially bad and were a result of algae growths in the pond. During two winters an ice layer on the pond in conjunction with the high oxygen demand of the organic matter in the pond, reduced the oxygen levels below the critical level killing numerous fish. The dead fish added further to the already poor water quality.

To gain some idea of the microbiological condition of this water, a microscope examination and a bacterial analysis were made in March, 1962. The low power microscope revealed large numbers of algae and protozoa. Five different types of algae (some motile) were found and at least four types of protozoa. The high power lens of the microscope revealed numerous bacteria. This was corroborated by the bacteria plate counts: total bacteria, greater than 3,000 spc/ml; thermodurics, greater than 3,000 per ml; thermophilic, greater than 3,000 per ml; psychrophiles, 65,000 per ml; and enterococci, over 1,100 per 100 ml. This high density of microorganisms indicates that there was a plentiful supply of food available and in turn that the organic content of the water must have been high.

The pressure rapid sand filter was 12 inches in diameter (Fig. 7). It was a standard water conditioner tank with sand instead of exchange resin for filter medium. According to the manufacturer's literature, this filter should have contained 50 pounds (dry weight) of gravel and 42 pounds of sand and have a maximum flow rate of 2.5 gpm and a minimum backwash rate of 6 gpm. The home owner reported that the filter was backwashed every couple weeks for 10 minutes and then rinsed for five minutes. From observations made at installation 8 and elsewhere, it would seem that more frequent and longer periods of backwashing would be needed to clean this filter. It is also rather doubtful that the recommended flow of 6 gpm was available for backwashing. The maximum flow through the filter registered a maximum of 2 gpm, or 1.56 gpm per square foot surface area, i.e., below the 2 gpm per square foot commonly recommended for rapid sand filters.

The arrangement of the system made it impossible to evaluate the intake and the filter as separate units and, therefore, they are discussed as one unit. In the first six sets of samples (7/58--3/59) the gravel box intake was in use. During this time there was a 49% reduction in turbidity, a 7% reduction in apparent color and a 98% reduction in coliform bacteria. However, the average effluent for turbidity was 19 units, for color 128 units and the median coliform density was 9.1.

In June 1959, a surface type intake was installed. This was a "homemade" unit constructed of a 3-foot section of perforated 1-inch pipe wrapped with fiber glass insulation and wire screen. It was suspended two feet below the surface of the pond from a floating can. In August 1959, this unit was replaced by a commercial surface intake (described under installation 1 and shown in Fig. 4).

Although only a few samples were taken with the "homemade" unit in use, the results seemed to indicate that the "homemade" and commercial units operated with roughly equal efficiency.

The surface intake filter combination produced a reduction in turbidity of 21%, and in color of 13%. The average effluent turbidity and color were 23 and 69, respectively.

Installation 90:

A section of perforated plastic pipe placed inside agricultural tiles and buried under two feet of gravel in the bottom of the pond was used as an intake at this installation. This was replaced in September, 1959, by a surface type intake (Fig. 23). Water was pumped from the intake and chlorinated in the basement of the house. A Wallace & Tiernan diaphragm pump-chlorinator was used to add household bleach to the water. This was later replaced (Aug. 1959) with a BIF Industries diaphragm chlorinator. Two tanks of 42-gallon capacity each (one a pressure tank and one a storage tank) followed the pump. Water for the livestock received no further treatment, while that used for domestic purposes passed through a pressure rapid sand filter. Water used in the kitchen received further treatment through an activated carbon filter. Water used elsewhere in the house did not receive this treatment (Fig. 22).

The physical and bacteriological quality of the raw pond water at this installation was about average (5). Algal growths were common in the summertime and may have been a cause of some of the color detected in the water.

Ten samples were taken (8/58 thru 8/59) with the buried-pipe intake in use. The intake reduced the turbidity on some occasions, while on others it was increased. Intake effluent samples taken in July, August, and September showed a decrease in turbidity while those during the months from November through June showed an increase. This increase in turbidity was probably due to sediment passing through the gravel layer over the buried pipe. It has been reported that in rapid sand filters sediment will pass through the filter during the winter because of increased shearing action resulting in turn from the increased viscosity of the colder water. Further, as the diameter of the sand increases, the greater the amount of sediment passing the filter (4). Insufficient data were collected to determine if the flow rate and water temperature (34 to 42°F.) observed were in the range to encourage this shearing action.

Apparent color was reduced little, if any, by this intake, the effluent water almost always having a high color concentration. Odors were also detected in the effluent water during the spring of 1959. Usually the water in the upper levels of the pond was of higher quality than the intake effluent, indicating the disadvantage of using the buried-pipe type of intake.

The poor quality of water obtained from the pond in the spring of 1959 prodded the owner into replacing the buried-pipe intake with a surface type. An experimental surface intake was designed and placed in use in September 1959 (Fig. 23). The performance of this intake decreased with time. The fiber glass filter unit was not changed after the intake was placed in use. Apparently sediment built up on the fiber glass and in time pulled into the distribution system. During the winter months the apparent color also increased. This may have been due to the decaying of the algae and other organic growths that accumulated on the intake during the summer. Odor was not detected in the water after the surface intake was installed.

The pressure rapid sand filter at installation 90 was similar to that at installations 88 and 89, but was made by a different manufacturer (Fig. 7). This filter was 15 inches in diameter and the manufacturer recommended a maximum flow rate of 8 gpm and a backwash rate of 10 gpm. The highest recorded flow rate was 5.25 gpm (4.3 gpm per sq. ft. surface area). The homeowner reported that he backwashed the filter monthly.

The activated carbon filter following the sand filter was 11 inches in diameter and had a recommended flow rate and backwash rate of 4 gpm. This filter contained $\frac{1}{4}$ to $\frac{1}{2}$-inch granules of activated carbon and was backwashed on the same schedule as the sand filter.

The efficiency of the rapid sand filter was evaluated only in the last 12 sets of samples with the surface intake in use. The turbidity was reduced in all but one case with an average reduction of 64%. Fifty-eight percent of the samples met the Standard for turbidity. Apparent color was reduced 73% and all of the samples met the Standard.

Only a small portion of the water used passed through the carbon filter. A water meter on the cold water line to the kitchen recorded an average daily use of 16 gallons and a maximum use of 22 gallons per day (occurred in August). Maximum flow rate was measured at 3.3 gpm. As in the case of the rapid sand filter, the carbon filter alone was evaluated only in the last 12 samples. During this period the turbidity was reduced 31% and the color 55%. All of the samples met the Standard for color and 83% for turbidity.

In the first ten sample sets when the buried-pipe intake was in use, the sand filter and carbon filter were evaluated as one unit. The combination of the two filters resulted in a 49% reduction in turbidity and 64% in color. However, only 40% and 30% of the samples met the Standards for turbidity and color, respectively.

The chlorine contact time in the influent water sample to the rapid sand filter was calculated to be 1.2 minutes*(obtained in a 42-gal. pressure tank and 42-gal. storage tank). The rapid sand filter added 4.5 minutes of contact, resulting in the filter effluent having a total contact time of 5.7 minutes. Water collected in the kitchen had an additional 1.7 minutes (total of 7.4 min.) during passage through the carbon filter and 25 feet of pipe. The chlorine residual in the water from the sand filter ranged between 0.0 and 4.0 with an average of 1.35 mg/l. On the two occasions when the residual was 0.0, the chlorinator was not operating properly. The owner had a great deal of trouble with this chlorinator because of the clogging of valves and lines with precipitates and the inaccuracy of the feed rate. Consequently, this chlorinator was replaced by a new one in August 1959. Six contaminated samples were obtained from the sand filter influent water. The chlorine residual of these samples ranged between 0.3 and 3.0 mg/l, giving a range of Ct factors of 0.36 to 3.6. At these chlorine residuals and contact time some coliform organisms could be expected to survive (Fig. 1).

* Based on flow rate of 3.3 gpm.

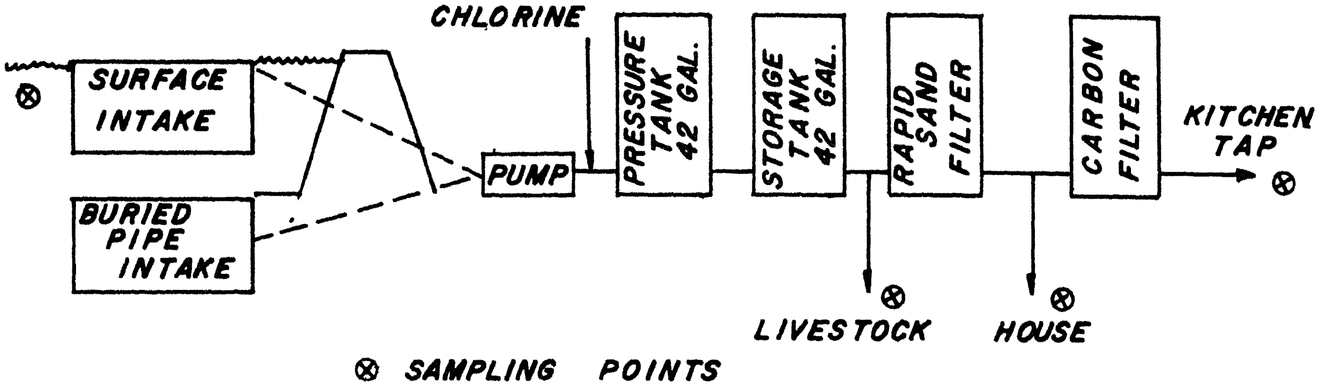


FIGURE 22. FLOW DIAGRAM OF WATER TREATMENT SYSTEM

INSTALLATION NO. 90

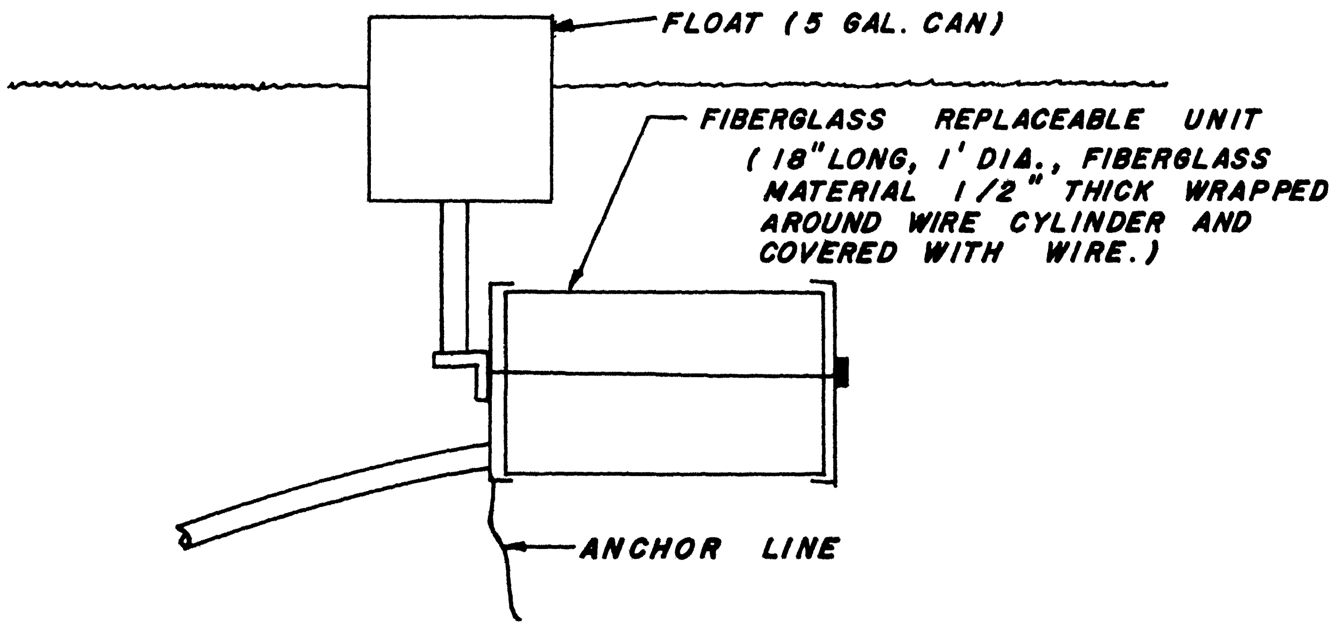


FIGURE 23. EXPERIMENTAL FIBERGLASS SURFACE INTAKE

INSTALLATION NO. 90

The sand filter produced an average reduction in chlorine residual by 60%, with the reduction in some cases as much as 100%. In three cases when the influent water was contaminated, the effluent water was not. This was probably because of the additional contact time in the filter and the filtering action of the filter. On the other hand, on four occasions when the influent was free of coliform bacteria, the effluent was contaminated. In two of these instances the sand filter had reduced the chlorine residual 100%; therefore, there was a good possibility that coliform bacteria may have been growing in the lower portion of the filter and seeded the water from this point. This, however, does not seem to be a reasonable explanation for the presence of coliforms in the remaining two samples, since coliforms are not likely to survive in water containing 0.2 and 0.8 mg/l of chlorine, unless they are quite chlorine-resistant.

The carbon filter reduced the chlorine residual 100% in all but two cases. Eight samples collected following the filter were contaminated. This would tend to indicate that the water was recontaminated occasionally as it passed through this filter. The water contained little or no chlorine residual by the time it reached this filter, and therefore, any bacteria that might have been in the carbon media would not have been destroyed.

SUMMARY AND DISCUSSION

The results presented show that all treatment systems were unsatisfactory in one or more respects. None of them produced high quality water at all times. It is not enough to say that the water is bacteriologically safe or is aesthetic 90% of the time; individual water systems should be capable of producing a water meeting the Drinking Water Standards (8) at all times.

In order to better understand the advantages, disadvantages, and operation of the different unit processes, it is necessary to evaluate each type of unit individually. Data from the twelve installations were combined so that each unit process, i.e., intake, filtration and disinfection, could be evaluated.

Intakes

The primary role of an intake should be to remove good quality water free from large particles of suspended solids that would cause clogging of water lines, impair pump performance, add extra burdens to treatment equipment, and produce undesirable characteristics in the water. Examples of such suspended solids are algae, fish, sand, leaves and pieces of wood. The intake need not remove fine suspended matter because this would necessitate frequent cleaning of the intake which is a difficult operation.

Basically there were four types of intakes observed in this study: (1) buried pipe, (2) concrete block box without gravel, (3) gravel-barrel and gravel-concrete block box, and (4) surface.

The buried-pipe intake was evaluated at installations 1 and 90 (Table II.). In both cases the intake was eventually replaced with a surface intake because of the high concentrations of color, turbidity and odor in the effluent water. The construction of this type of intake, in which a section of perforated pipe is buried in the bottom of the pond and backfilled with gravel or soil, was based upon the idea that the gravel or soil would filter the water before it reached the pipe. However, the buildup of sediment and organic matter on the bottom of the pond was not taken into consideration. Soluble organic material formed in this layer of sediment and was carried into the intake, resulting in an increase in color and odor. Also, apparently channels formed in the gravel or soil overlay through which silt was carried into the intake pipe. The buried pipe intake proved unsatisfactory.

The concrete-block-box without gravel was employed at installation 62 only. This intake gave some decrease in color and turbidity, partially by the filtering action of the concrete blocks as the water percolated through. A modification of the intake design with water removed from a point near the surface of the water inside the box would eliminate the problem of the settled suspended solids being drawn into the distribution system. Also, some provision might have to be made for periodic removal of the accumulated sludge from the intake. This intake appeared to perform satisfactorily.

Barrels or concrete block boxes filled with gravel and set on the bottom of the pond constitute the most common type of intake found in Ohio. These intakes were originally designed and installed for the purpose of supplying water to livestock and not for domestic uses. Livestock do not require a water of high physical quality. Nine ponds initially had this type of intake. In three cases these intakes were replaced by a surface intake. The average effluent turbidity from these intakes was relatively good, while the color and odor left much to be desired in a majority of the ponds (Table II). In general, the effluent turbidities were comparable with those obtained using the surface intake, but the color and odor concentrations were higher. Since color and odor are more difficult to remove than turbidity and requires special equipment in many cases, it is wise to keep them to a minimum. This type of intake did not appear to be satisfactory for the removal of water intended for domestic use.

None of the installations originally had a surface intake. However, at five installations a surface intake was installed after poor quality water was obtained from the original intake. The turbidity of the effluent was not greatly improved by the surface intake, in fact, in a few cases it was of poorer quality. As seen in Table II, the color concentrations of effluent water were lower with the surface intake even though the surface intake appeared to increase the color content. Odor was not detected in any of the samples obtained from the surface intakes.

The surface intake soon after installation became covered with layers of slime, algae and sediment. Some of this material undoubtedly was carried into the distribution system. These data indicate that the fiber glass or ceramic units should be changed more often, thereby placing some limitation on the use of this type intake, as frequent maintenance is undesirable. An intake on which slime, algae and sediment would not collect would be an important improvement over the present intake. However, almost any item placed in a pond usually becomes covered with these slime layers. A fine screen might serve just as well as fiber glass.

Additional information was obtained on intakes in experiments conducted at the Southern Substation of the Ohio Agricultural Experiment Station. In a three-acre pond three different types of intakes were installed: (1) surface intake, (2) gravel barrel intake, and (3) buried pipe intake. Two types of surface intakes were tested, a "homemade" unit constructed from a section of perforated pipe wrapped with fiber glass and coarse screen and a commercial fiber glass unit (illustrated in Fig. 4). The barrel intake was composed of two 50-gallon steel drums filled with gravel similar to that in Fig. 6. The buried pipe intake was constructed by burying 600 feet of perforated $1\frac{1}{4}$-inch plastic pipe 12 inches deep in the bottom of the pond. Table III presents data on the effluent water quality from these intakes.

In all respects the effluent from the surface intake resulted in a higher quality of water and the buried pipe intake the lowest quality. As the results in Table IV show, the higher quality of the effluent was not due to superior filtration by the intake, but simply was a function of the location of the intake in the pond. All three intakes appeared to function as a reservoir for turbidity and color since the effluent contained higher concentration of this material than the influent. The increase in turbidity and color was probably due to sediment being flushed out of the intake. In tests performed on a number of occasions, the concentration of turbidity and color was noted to increase with flow rate. These results indicate that the surface intake removed a superior quality of water and therefore, is the method of choice, although the concrete block box without gravel appeared to perform as well if not better.

TABLE II. Effect of Intake on Water Quality

Installation No.	Turbidity: Average Effluent	Turbidity: % Reduction	Color: Average Effluent	Color: % Reduction	% Effluent Samples with Odor
Concrete block box without gravel intake--					
62	12	31	19	40	2
Buried pipe intake--					
90	40	17	102	8	22
Barrel and concrete block box filled with gravel intake--					
6	24	23	95	+9(a)	48
8	23	57	71	10	17
25	13	32	29	0	4
86	10	17	39	5	13
Surface intake--					
8(b)	15	+4	36	+16	0
8(c)	27	+15	47	+31	0
86	15	12	22	24	0
90	38	+153	46	+130	0

(a) + Indicates a % increase.
(b) Homemade surface intake.
(c) Ceramic surface intake.

TABLE III.

Comparison of Effluent Quality of Barrel, Surface, and Buried Pipe Intakes

	Turbidity (units)	Color (units)	% Samples with Odor	Coliform Bacteria (mpn/100ml)[a]	Coliform Bacteria No. Samples
Surface	12.3	34.7	5	15	73
Barrel & Gravel	19.9	44.7	10.8	23	99
Buried Pipe	49.4	105	26.5	23	55

(a) Median values.

TABLE IV.

Surface, Barrel, and Buried Pipe Intake Performance

	Turbidity			Color		
	Influent	Effluent	%Increase	Influent	Effluent	%Increase
Surface	11.2	12.3	9.8	29	34.7	19.7
Barrel & Gravel(a)	13.4	19.9	48.5	36.8	44.7	21.5
Buried Pipe(b)	25	49.4	97.5	69.5	105	51.1

(a) Values for influent sample taken as an average of samples 2,3,4,5 feet above bottom of pond.
(b) Influent sample was taken as sample one foot above bottom of pond.

Filters

The role of a filter in a pond water system should be to reduce the sediment load to the extent that the effluent water has a turbidity concentration meeting the Drinking Water Standards (8). Apparent color caused by suspended matter should also be removed. In addition, a filter for an individual water system should be simple to operate and to clean, have little maintenance, and be economical. Other features that might be incorporated in a filter are provisions for the removal of true color, tastes, odor and chlorine. In cases when the chlorine is reduced or eliminated, the water should not be recontaminated either by the filter or in the distribution system following the filter.

Four types of filters were investigated. These were classified under the following criteria: (1) slow sand filter--flow rate less than 100 gallons per day per square foot surface area--gravity flow, (2) rapid sand filter--flow greater than 100 gallons per day per square foot surface area--gravity flow or under vacuum, (3) pressurized rapid sand filter--flow rate 1 gallon per minute per square foot surface area or more--closed system with flow under 20-60 psi pressure, (4) carbon filter--filters in which the filter medium was partially or completely carbon--under 20-60 psi pressure.

Table V summarizes the filter results. In situations where the effect of the filter could not be isolated from the intake, the results include the effect of the intake. Some differences can be expected, but the final conclusions would be the same. Sand filters without pretreatment reduced the average turbidity less than 50% and the color less than 40% except at installation 90. Sixty percent or less of the samples met the Drinking Water Standards for turbidity and color. The only exceptions were at installation 8, which had a high quality influent water, and at installation 90. Results clearly indicate that the rapid sand and pressurized sand filters were not adequate in producing a high quality water suitable for domestic use. Similar results were obtained for the slow sand filter; however, the management of the filter studied was poor. Research by other investigators and by the authors indicate that these results are not indicative of those normally given by the slow sand filters.

Where chlorine was added before a sand filter, a large percentage of the chlorine was removed by the filter. The chlorine was probably reduced by the chlorine demand of the organic matter trapped in the upper layers of the filter. This reduction should be taken into account when chlorine dosages are determined.

Major problems encountered with these filters were (1) the suspended solids were of such nature and size that the filter was unable to remove them, (2) inadequate backwashing and maintenance was due to low capacity pumps as well as apathy of owner toward equipment, (3) equipment not suitable for the use to which it was being put, and (4) need of some type of pretreatment. If rapid sand and pressure-sand filters (most commonly used today) are to be used for the treatment of pond water, further investigations are needed to develop methods of improving their performance. Pretreatment, such as that in municipal plants, is the most obvious solution to the problem.

Pretreatment with alum as carried out at installation 8 shows promise of improving the performance of the pressure sand filter. Other studies by the authors indicated that this methdd is successful. However, further research is needed to further develop the method and to gain an understanding of the mechanisms involved.

Carbon filters investigated were purchased by the owners primarily to remove chlorine from the water. They removed chlorine effectively as well as reducing the turbidity and color to some degree. In fact, they were more efficient than sand filters in most cases. High turbidity of the influent water was the cause of the rapid reduction of flow rate and plugging of these filters. An efficient primary treatment system would increase the life and in turn decrease the maintenance cost of these filters. The recontamination of water was another problem with this type of filter. In cases where care was not taken in installing the unit, it was contaminated and clean water that subsequently passed through the filter was recontaminated. Since the filter removed the chlorine, there was no means of destroying bacteria established in the filter. However, after a period of time the bacteria died and uncontaminated water was again obtained.

TABLE V. Summary of Filter Results

Type of Filter	Installation No.	Approx. Flow Rate per sq.ft(h)	Turbidity: Avg. Infl.(i) units	Turbidity: % Reduction (a)	Turbidity: % Samples Meeting Standard(b)	Apparent Color: Avg. Infl. units	Apparent Color: % Reduction (a)	Apparent Color: % Samples Meeting Standard(b)
SAND FILTERS								
slow	26	100 gpd	24	33	35	31	+52(c)	52
rapid	1	360 gpd	22	45	52	36	6	58
rapid	23	144 gpd	49	35	4	96	10	8
rapid	25	175-610gpd	13	23	40	30	17	57
pressure-rapid	8	1.8 gpm	17	45	81	38	40	72
pressure-rapid	88	----	(d)	--	55	--	--	80
pressure-rapid	89	1.6 gpm	31	32	25	97	10	0
pressure-rapid	90	4.3 gpm	36	63	58	41	76	100
SAND FILTER WITH PRETREATMENT								
pressure-rapid	8(f)	1.8 gpm	11.4	44	86	37	58	81
CARBON FILTERS								
precoated	1	(e)	15	40	58	83	90	91
precoated	8	0.07-0.83 gpm(g)	9	59	90	22	63	92
precoated	23	(e)	31	84	96	86	98	96
precoated	88	(e)	10	54	95	11	72	95
pressure	90	2.0 gpm	36	31	85	41	55	100

(a) effect of intake was ignored.
(b) turbidity, 10 units; color, 20 units (8).
(c) "+" indicates an increase and not reduction.
(d) no means of determining flow rate or influent quality.
(e) flow rate usually less than 1 gpm after unit in use short time.
(f) alum fed before filter.
(g) flow rate for filter ranged between 0.2 and 2.5 gpm. Filter had 3 sq.ft. surface area.
(h) gpd--gallons per day; gpm--gallons per minute.
(i) infl.--influent.

Disinfection

The role of disinfection in the individual water treatment system is the destruction of all pathogenic organisms. A desirable supplemental activity is the reduction in population of those organisms that cause damage to food products that may be produced in the home or on the farm, for example, milk and home canned foods. The disinfection equipment should be simple to operate, require little maintenance, be safe to use and be reasonably priced.

Disinfection with chlorine as practiced at these installations was poor. Between 18 and 74% of the treated water samples were contaminated i.e., contained more than 3 coliforms per 100 ml.(Table VI.) Batch chlorination was the most ineffective with more than 50% of the samples having no chlorine residual and with over 60% of the samples contaminated. This method places a great responsibility on the owner who usually does not understand the many facets of chlorination. Daily checks of the chlorine residual would be the only reliable way of assuring uncontaminated water.

The results from those installations using automatic chlorinators were disturbing. From 5 to 22% of the samples contained no chlorine, for one or more of the following reasons: (1) insufficient chlorine fed to meet the chlorine demand of the water, (2) chlorine supply exhausted, and (3) chlorinator not operating. The first two reasons could be eliminated by more careful attention and by educating the operator. The chlorinator malfunctions were primarily due to: (1) breakage of plastic and nylon parts, (2) clogging of lines and valves, and (3) other unusual mechanical defects. Breakage of parts could be reduced either by the manufacturing them of a more durable material or by educating the owner not to over tighten or use pipe wrenches on this material. Clogging of lines and valves could be reduced by: (1) placing an intake in the chlorine supply reservoir that removes the solution from near the surface instead of near the bottom where sediment collects, (2) mixing the chlorine with water that has a low mineral content, and (3) adding polyphosphate to the chlorine solution. The polyphosphate prevents sediment from precipitating out of solution. The mechanical failures of the chlorinator are those that can be expected of any machine.

The large number of contaminated samples was also disturbing, for it would be hoped that noneof the samples would be contaminated. A reliable disinfection system should have 100% non-contaminated samples, not 50 to 82% as observed. In addition to the lack of chlorine, possible reasons for contaminated samples were: (1) insufficient chlorine and/or contact time, (2) alkaline pH, (3) low temperature, (4) high turbidity, (5) resistant coliform or coliform-like organisms, or (6) a combination of these and other factors.

As discussed earlier, a proper combination of chlorine concentration and chlorine-water contact time is essential to prevent contamination. Normal recommendation for municipal and military water supplies is 0.2 ppm of chlorine with a 30 minute contact time or a Ct factor of 6. As shown in Fig. 1, coliform bacteria would be expected to be killed at this level and with some measure of safety. Data from eight of the installations gave reliable information about several disinfection methods. All treated samples that contained chlorine and yet were contaminated were investigated to determine reasons for contamination. Seventy-five samples were investigated of which 43 (57%) had Ct factors of less than 5.

Contamination of these samples was considered to be the consequence of insufficient Ct factor. The remaining samples were tabulated to determine whether turbidity, temperature, pH, or a combination of these factors were responsible for the contamination (Table VII). As temperature decreases and pH increases, chlorine becomes less effective as a disinfecting agent and either more contact time or greater chlorine residual is needed to assure a kill, i.e., a larger Ct factor is required. Where turbidity concentration is high, there is a greater possibility that bacteria may be entrapped in a particle of suspended solids and protected from the chlorine. Of the 11 contaminated samples in the Ct range of 5-10 (Table VII) only four appear to be remotely affected by these factors. A combination of low temperature and high turbidity occurred in 3 of the 4 samples. The remaining samples in this range and in the remaining ranges have no apparent characteristics that explain why they were contaminated. The relatively high turbidity of the 4 out of 5 samples with Ct factors greater than 35 suggests that possibly turbidity was the cause.

The 32 contaminated samples with Ct greater than 5 indicate that other factors besides those considered are involved. The chemical and physical properties of farm pond water are not different from other surface waters, in fact, pond water is usually of better quality. The results suggest the possibility of chlorine resistant coliform and/or coliform-like organisms in the water.

The results obtained in the study of the effects of treatment upon the populations of the various groups of bacteria in pond water are summarized in Table VIII. The median values for the individual ponds, as well as the median of medians for all ponds, emphasize the high quality of the raw pond water itself. The numbers of thermodurics, thermophiles, and psychrophiles in the pond water appear to be rather insignificant. The densities of the enterococci and the coliforms (Table VI) again indicate a rather low level of pollution.

The median values for the individual installations reveal a great inconsistency in the reduction of the populations of the various groups by treatment. This, of course, merely reflects the inconsistencies in the treatment processes which were described above. The median of medians for each bacterial group except the thermophilics, however, reveals that the overall effect of treatment was a definite reduction in bacterial density.

In general, populations of thermophiles, thermodurics and psychrophiles were so low that they would be unlikely to create any problems in the normal use of water. The median total bacterial density in finished water at certain installations was somewhat higher than the 100 per ml recommended by Atherton, et al. (1) for water to be employed in milk houses. In most cases, reduction in enterococci counts were in line with coliform reductions, although these organisms appeared to be somewhat more resistant to treatment than the coliforms.

TABLE VI. Summary of Disinfection Results

No. Instal-lation	Median Coliform Bacteria, mpn/100ml Raw Water	Effluent Water	% of Samples Contam-inated	Free Available Chlorine, mg/l max.	min.	median	% Samples without Chlorine Residual	Approx. Contact Time, min.	Approx. Ct Factor (c)
BATCH CHLORINATION									
25	215	7.3	62	4.0	0	0	70	--	--
26	93	9.1	74	6.0	0	0	54	--	--
AUTOMATIC CHLORINATION									
1	43	<3	26	16.0	0	4.5	16	3.6	16.4
8	190	3.6	53	5.0	0	1.5	5	1.7	2.55
8(a)	75	<3	18	5.6	0	0.9(b)	6	11.0	9.9(b)
23	160	<3	29	10.4	0	1.4	8	9.8	13.7
62	9.1	≤3	32	5.0	0	0.2	22	0.42	0.08
86	75	<3	43	1.5	0	0.4	9	0.64	0.26
87	240	<3	50	>9.0	0	1.0	13	0.08	0.08
88	121	<3	32	7.0	0	3.6	5	0.8	2.88
90	160	<3	42	4.0	0	1.1(d)	11	7.4	3.74(d)

(a) system expanded to include filter.
(b) residual 0.9 at point of chlorine application, but had a median of 0.0 mg/l at point of sampling. A residual of 0.45 mg/l was used to determine Ct factor.
(c) product of contact time and median chlorine.
(d) at point of chlorine application. A residual of 0.6 was used to determine Ct factor.

TABLE VII. Factors Affecting Contaminated Samples (a)

Ct Factor (b)	No. Samples	Contaminated Sample Analysis																	
		Sample			Sample			Sample			Sample			Sample			Sample		
		T(c)	TB(d)	pH	T	TB	pH	T	TB	pH	T	TB	pH	T	TB	pH	T	TB	pH
<1	29																		
1-5	14																		
5-10	11	50	20	--	70	19	--	52	24	--	37	--	--	53	48	--	72	5	--
		71	12	7.9	72	4	7.4	64	18	--	57	9	8.0	69	4	7.9			
10-15	5	65	17	8.2	72	3	--	66	4	7.7	64	8	--	69	4	--			
15-20	3	65	4	8.6	74	5	--	73	1	--									
20-25	0																		
25-30	6	68	9	--	53	14	--	57	27	--	62	19	--	60	22	--	72	2	--
30-35	2	61	15	--	68	2	--												
35-40	3	71	1	--	68	22	--	--	50	--									
>40	2	66	24	--	40	38	--												
Total	75																		

(a) treated samples from installations 1,8,23,62,86,87,88,90 which were contaminated and had a chlorine residual were chosen for this table.
(b) Ct factor--chlorine concentration x contact time.
(c) T -- temperature (^{o}F.).
(d) TB -- turbidity (units).

TABLE VIII.

Summary of Median Bacterial Populations of Raw and Treated Water

Installation Number	Total Bacteria (SPC/ml) Raw	Total Bacteria (SPC/ml) Treated	Thermodurics (per ml) Raw	Thermodurics (per ml) Treated	Thermophilics (per ml) Raw	Thermophilics (per ml) Treated	Psychrophilic (per ml) Raw	Psychrophilic (per ml) Treated	Enterococci (MPN/100ml) Raw	Enterococci (MPN/100ml) Treated	Free Available Chlorine, mg/l	No. Samples
1	190	20	19	7	3	2	19	1	11	<3	>4.0	13
8	225	155	22	2	3	2	3	1	2	<3	0.6(a)	20
23	420	60	66	3.5	3	2	43	1.5	33	<1.8	0.3	5
25	110	140	17	14	1	1.5	7	3	49	2.8	0.0	5
26	310	550	15	18	4	5	14	130	2	8	0.0	5
62	120	105	14	15	1	2	2	1	13.5	2	0.0	14
86	220	55	20	16	2	5	11	2	49	2.7	0.6	6
87	140	165	188	61	48	23	11	1.5	29	5.7	1.0	6
88	240	60	93	13	16	5	497	6.5	205	12.4	2.5	4
Median of Median	220	105	20	14	3	5	11	1.5	29	2.7	0.6	--

(a) at point of application.

CONCLUSIONS

Twelve farm pond water treatment systems were evaluated over a 2 3/4-year period. These systems were constructed and maintained by home owners. The following conclusions were drawn from this study:

(1) None of the 12 systems produced a continuous supply of water that met the Drinking Water Standards (8).

(2) The two major problems were poor filtration and disinfection.

(3) The slow sand filters and rapid sand filters investigated were not effective in reducing the turbidity and apparent color to a suitable concentration when raw water quality was poor. Pretreatment with alum before filtration with a rapid sand filter improved its performance.

(4) Carbon dechlorinators were effective in reducing turbidity, color, odor, and chlorine, but had limited life. Where chlorine was fed before a sand filter, the filter reduced the chlorine concentration.

(5) Chlorination was not effective primarily because of the shortage of chlorine-water contact time in home water systems, apathy of the home owner, and other factors yet to be identified.

(6) Surface intakes in the pond and a concrete block box without gravel produced better quality water than other methods of removal.

RECOMMENDATIONS FOR FURTHER RESEARCH

The results of this study indicated that there are areas that need further investigation. Those areas of primary importance are:

(1) A concentrated investigation to determine the reasons for coliform survival with treatment that appears adequate according to our present knowledge.

(2) Development of methods for obtaining adequate chlorine-water contact time in the household water system and/or other methods of improving the disinfection of these water supplies.

(3) Investigations of the mechanics of filtration, such as the effect of the raw water characteristics, so that filtration techniques applicable to home water plants can be developed.

(4) Further studies on improvement of pressure-sand filter performance by pretreatment with a flocculating agent, including method of application, type of flocculation agent, and effects on chemical quality of water treated in this manner.

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APPENDIX A

Physical and Bacteriological Quality of Water

	Installation Number													
	1	6	8A	8B	8C	23	25	26	62	86	87	88	89	90
Turbidity, units, avg.														
Raw Water	22	31	39	15	11	49	19	24	16	14	27	16	31	30
Treated Water	12	24a	23	10	7	32	10	17	12	14	14	10	21	13b
Apparent Color, units, avg.														
Raw Water	36	87	56	44	37	96	28	31	30	33	32	31	97	66
Treated Water	34	95a	51	23	16	85	25	48	19	28	20	11	87	11b
Coliform Bacteria, MPN/100 ml, median														
Raw Water	23	350	190	93	22	160	215	93	9	75	240	121	390	160
Treated Water	<3	---	3.6	<3	<3	<3	23	9	<3	<3	<3	<3	119	<3b
Free Available Chlorine, mg/l, median														
Treated Water	>4.0	---	1.0	0.0	0.0	1.4	0.0	0.0	0.2	0.4	1.0	3.6	---	0.5b
Chlorine Contact Time, Min.	3.6	---	---	2.4	2.4	9.8	---	---	---	0.6	0.1	4.8	---	7.4
Beginning Date of Sampling	May 1958	May 1958	May 1958	May 1960	Jan 1962	July 1958	July 1958	July 1958	July 1958	July 1958	July 1958	July 1958	July 1958	Aug 1958
Ending Date of Sampling	Oct 1962	Sept 1961	May 1960	Jan 1962	Feb 1963	Mar. 1962	June 1961	Mar 1961	Aug 1962	Mar 1962	Mar 1962	Aug 1961	Mar 1962	May 1961

a Samples from stock watering tank below pond.
b Samples taken after sand filter.

APPENDIX B

Median Bacterial Population of Raw & Treated Pond Water

	Installation Number							
	1	8	23	25	26	86	87	88
Total Bacteria SPC/ml								
Raw Water	190	225	420	110	310	220	140	240
Treated Water	20	155	60	140	550	55	165	60
Thermodurics per ml.								
Raw Water	19	22	66	17	15	20	188	93
Treated Water	7	2	4	14	18	16	61	13
Thermophiles per ml.								
Raw Water	3	3	3	2	4	2	48	16
Treated Water	2	2	2	2	5	5	23	5
Psychrophilics per ml.								
Raw Water	19	3	43	7	14	11	11	497
Treated Water	1	1	2	3	130	2	2	7
Enterococci MPN/100 ml.								
Raw Water	11	2	33	49	2	49	29	205
Treated Water	<3	<3	<2	3	8	3	6	12
Free Available Chlorine mg/l	>4.0	0.0	0.3	0.0	0.0	0.6	1.0	2.5
Beginning Date of Sampling	Apr 1961	Apr 1961	Apr 1961	Apr 1961	Apr 1961	Apr 1961	Apr 1961	May 1961
Ending Date of Sampling	Oct 1962	Feb 1963	Aug 1961	Aug 1961	Aug 1961	Mar 1962	Mar 1962	Aug 1961

APPENDIX C

Effect of Dechlorination* on Water Quality

	Installation Number			
	1	8	23	88
Turbidity, units, avg.				
Before	15	9	31	10
After	9	4	5	5
Apparent Color, units, avg.				
Before	83	22	86	11
After	8	8	2	3
Coliform Bacteria, MPN/100 ml, median				
Before	<3	<3	<3	<3
After	<3	<3	<3	<3
Free Available Chlorine, mg/l, median				
Before	8.5	0.0	1.8	3.6
After	0.0	0.0	0.0	0.0
Beginning Date of Sampling	May 1958	May 1960	July 1958	July 1959
Ending Date of Sampling	July 1962	Oct 1962	Mar 1962	Aug 1961

* Commercial activated carbon dechlorinators.